

Thermal Battery Operating Gas Atmosphere Control and Heat Transfer Optimization

by Frank C. Krieger and Michael S. Ding

ARL-TR-6156 September 2012

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Thermal Battery Operating Gas Atmosphere Control and Heat Transfer Optimization

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techniques are reported. These results show that the volumetric energy densities of most presently fielded munitions thermal batteries can be increased by factors ranging from 1.5 to 3 if hydrogen gas can be removed. Zirconium (Zr) based gas getters					
are highly effective in atmospheres of pure hydrogen and are potentially useful in mixtures of hydrogen and air. Barium					
chromate (BaCrO ₄) placed in contact with heat paper made from Zr/BaCrO ₄ heat powder forms an effective oxidizing ash for					
hydrogen gas when the heat paper is ignited. Because the oxidizing ash is not present until the battery is initiated there is no					
need to protect a chemically active surface during the required 20-year storage lifetime. Water formed from the					
hydrogen/oxidizing ash reaction did not react to form additional hydrogen during LCCM thermal battery operation.					
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1. Introduction

The primary thermal reserve batteries used in munitions are highly reliable one-time-use-only power sources with typical lifetimes of 5 min or less and required shelf lives of as long as 20 years that are assembled into bombs and missile or artillery rounds during manufacture. The batteries are hermetically sealed and have high operating voltaic cell temperatures (400–600 °C). The batteries are typically activated simultaneously with the ordnance device by heating the electrochemical cells to their operating temperature using a fixed amount of pyrotechnic material. The electrochemical cells then become active and the electrochemical-heat-source stack begins to cool through a thermal insulation package.

As presently manufactured, these batteries are ordinarily heat limited and contain excess active electrochemical material, which also serves as an internal heat reservoir. When the batteries are heat limited, the electrochemical cells simply cool below their required operating temperature before the available electrochemical lifetime can be supplied. Because extra electrochemical material is already present, simply reducing heat loss rates can increase battery lifetimes for many fielded applications.

For munitions thermal reserve batteries, the emphasis is usually on volume reduction rather than on weight reduction. Control of the operating atmosphere gas quantities and chemical compositions, when used with mathematical modeling, can increase the volumetric energy densities (reducing the required sizes) of most presently fielded munitions thermal battery applications by factors ranging from 1.5 to 3 (I–3). High thermal conductivity hydrogen gas evolved during battery initiation and operation can be removed by the oxidation of hydrogen gas to water or by gas gettering methods.

The oxidizing ash of zirconium (Zr)/barium chromate (BaCrO₄) heat powders with low Zr percentages (~21/79 w/o (weight percent) Zr/BaCrO₄) has long been known to produce small quantities of hydrogen gas (4). The reducing ash formed from Zr/BaCrO₄ powders with high percentages of Zr (~28/72 w/o Zr/BaCrO₄), by contrast, has long been known to produce large quantities of hydrogen gas. This suggests that BaCrO₄ could be processed into or placed in contact with existing heat paper powder formulations where it would oxidize hydrogen gas and form water when the heat paper is initiated. The resulting Zr/BaCrO₄ powder mixtures could then serve as low-cost, previously well-characterized, readily available hydrogen gas oxidizing agents in presently fielded thermal batteries.

Operating gas atmosphere chemical composition tests have shown that water liquid and vapor present in the operating Low Cost Competent Munition (LCCM) thermal reserve battery did not react with chemically active battery components to produce significant quantities of hydrogen gas (1, 2, 5). It should be noted, however, that LCCM had a massive outer case that remained near

-40 °C during battery operation. The possible extent of this reaction must be investigated more thoroughly, especially for thermal batteries with higher case operating temperatures. Traditional methods of gas control, including materials selection, chemical processing, internal heat balancing, and internal construction methods, should be used initially, so that hydrogen gas oxidation or gettering need remove only a minimal amount of hydrogen.

Because the lifetimes of munitions thermal reserve batteries are short (typically 1 to 3 min), any hydrogen gas evolved during battery initiation and operation must be removed rapidly. Hydrogen gas can be removed quickly both by oxidation using BaCrO₄ heated to high temperatures with heat papers or powders and by using gas getters. Zr-based gas getters can remove hydrogen gas rapidly from atmospheres of pure hydrogen. Zr-based gas getters are less efficient, but are still usable in hydrogen/air gas mixtures. Only small quantities (1 to 3 g for LCCM) of either BaCrO₄ or Zr-based gas getter material (easily incorporated into the battery during manufacture) are needed to remove the required quantities of hydrogen gas (~50 std-atm-cc or 4.50 mg of H₂ for LCCM).

Present munitions thermal reserve batteries are hermetically sealed in dry room air at a dew point of –40 °C or lower during manufacture. Measurements of operating thermal reserve battery gas atmosphere chemical compositions show that the complete removal of hydrogen gas from those batteries, combined with appropriate thermal modeling and optimization, can reduce global thermal insulation conductivity values (and thereby increase the electrical lifetimes) by factors ranging from 1.5 to 3. Measured global thermal conductivity values and thermal models show that even partial removal of the hydrogen gas can produce significant increases in the volumetric energy densities (size reduction) of munitions thermal batteries. Significantly greater improvement is possible by backfilling the batteries with low thermal conductivity gases such as argon (Ar), krypton (Kr), and xenon (Xe), but the focus of this report is on the removal of high thermal conductivity hydrogen gas from presently fielded thermal batteries. The reaction rates of gas getters with mixtures of hydrogen and inert gases such as Ar, Kr, or Xe, and of hydrogen gas with small quantities of commonly encountered thermal battery gas atmosphere contaminants (O₂, N₂, CO, CH₄, and CO₂) will be investigated in the near future.

2. Experimental

Gas evolution and LCCM thermal conductivity measurements and analyses were done as described previously (2, 5), using an Agilent 34970A Data Acquisition/Switch Unit (typically 10 readings/s), MKS Baratron dual capacitance manometer pressure transducers, an Agilent 7890A gas chromatograph with a thermal conductivity detector, and type K thermocouples. A stainless steel (SS) tube was used as a chemical reaction vessel for the gas gettering experiments. The SS tube was heated using a Lindberg/Blue M model number TF55035A–1 tube furnace from

Thermo Fisher Scientific (maximum operating temperature 1100 °C). The SS tube was enclosed in a protective quartz tube to insure proper operation of the tube furnace.

Chemicals were processed in the U.S. Army Research Laboratory (ARL)/Adelphi dry room at a nominal dew point of –56 °C (0.074% relative humidity at 70 °F). ARL processed and purchased chemicals were dried in a Yamato ADP 21 Vacuum Drying Oven using a Model RVT 400 – 115 Refrigerated Vapor Trap from Thermo Electric Corporation (nominal cold trap temperature –50 °C) and a Uniweld UVP4 vacuum pump that could deliver a minimum pressure of nominally 50 microns of mercury (6.7 Pa). Most heat papers, heat powders, and gas getters used were from commercial vendors, or were fabricated in-house at ARL/Adelphi. One of the older (ca. 1960) Zr/BaCrO₄ heat powders originally came from the old National Bureau of Standards in Washington D.C., and showed similar gas evolution properties to those previously reported (4), as expected. Chemicals were weighed using an AWS AL-201S Analytical Balance or a Mettler Toledo AT 20 Microbalance. The BaCrO₄ used was certified grade from Fisher Scientific. Global measured leak rates of the entire evacuated gas handling system, as used in the various experiments, were typically measured by pressure readings taken over periods of several days or weeks and ranged from 5.3 E–5 to 6.3 E–6 std-atm-cc/s.

A schematic of the previously reported modified gas handling system used is included in this report to facilitate an understanding of the gas volume measurements (I, 2). All of the gas and gas handling system volumes were measured relative to the volume of the 10-cc sample bottle, using the ideal gas law. The 10-cc sample bottle volume was accurate to $\pm 10\%$. Absolute gas quantities were therefore measured to an accuracy of approximately $\pm 10\%$. Relative gas quantities, however, and gas volumes relative to the 10-cc sample bottle, could be measured to a precision of better than $\pm 0.1\%$ using the dual capacitance manometers. Relative hydrogen quantities could be measured to an accuracy of better than $\pm 0.1\%$ if the gas measured was known to be pure hydrogen.

3. Experimental Global LCCM Thermal Insulation Package Thermal Conductivity Values

Global thermal conductivity values of the thermal insulation package of fully assembled LCCM thermal batteries were measured in various gas atmospheres using quasi-steady-state and transient heat transfer methods as previously described in reference 1. The lowest thermal conductivity components of that thermal insulation package consist mostly of finely divided silica particles along with other finely divided particles such as titanium dioxide to reduce radiation heat transfer. A large portion of these low thermal conductivity thermal insulators (~90 v/o [volume percent] is simply void volume that will be ordinarily be filled with the gas that is in the surrounding atmosphere. Radiation and convection heat transfer through these lowest thermal conductivity thermal insulators (and through the entire LCCM thermal insulation

package) are both minimal. The measured thermal conductivity values from the cooling curves of this report can be used directly to determine the total amount of heat lost through the LCCM thermal insulation package at the reported thermal insulation package temperatures as explained in appendix A and reference 1. Representative results of those thermal conductivity measurements are shown in figure 1.

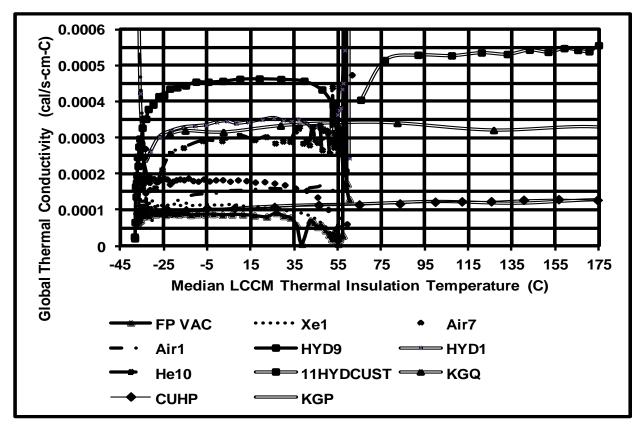


Figure 1. Measured global thermal conductivity values for the LCCM thermal insulation package in selected gas atmospheres. Legend numbers are nominal gas pressures in absolute atmospheres. Three of the four curves that include data above 60 °C are quasi-steady-state data from two operating LCCM thermal batteries and from the copper-heat pellet stack using the LCCM thermal insulation package. For low thermal conductivity gases, heat losses through the solid portions of the thermal insulation package become more significant.

Note: FP VAC = fore pump vacuum (~6.7 Pa), Xe = xenon, HYD = hydrogen, He = helium, 11HYDCUST = copper-heat pellet stack (LCCM simulation) high temperature transient heat transfer experiment at 11 atmospheres pure hydrogen absolute, KGQ = operating LCCM thermal battery GPS9Q, CUHP = operating copper-heat pellet stack (LCCM simulation, quasi-steady-state experiment), KGP = operating LCCM thermal battery GPS9P.

Quasi-steady-state measurements used operating LCCM thermal batteries, as well as a copper-heat pellet stack where copper disks simulated the thermal cell stack, both geometrically and thermally. An LCCM thermal battery (or copper-heat pellet stack) was built into a reusable LCCM case test fixture, insulated with an LCCM thermal insulation package, and fitted with a gas handling system. Type K thermocouples were spot-welded to SS disks in the LCCM cell

stacks and to SS disks placed in the copper-heat pellet stack. A type K thermocouple was packed firmly into a 1/8-in-diameter thermocouple well drilled into the side of the SS reusable LCCM case test fixture using glass electrical tape (Scotch #69) and mica for both types of tests (LCCM and copper-heat pellet stack). The pyrotechnic materials were ignited and the LCCM electrochemical-heat-source voltaic cell stacks then functioned normally while cooling through the thermal insulation package. After heat pellet ignition, the copper-heat pellet stack rose to a maximum temperature of about 500 °C, and then cooled normally through the thermal insulation package. Global LCCM thermal insulation package thermal conductivity values were then measured from the resulting temperature-time curves of the LCCM battery and copper-heat pellet stacks and cases using the known geometric configurations and component heat capacities as described in detail in reference 1.

After the initial quasi-steady-state test of the LCCM battery designated GPS9SU was complete, the transient tests were done by moving the GPS9SU reusable test fixture filled with various gas atmospheres between two Tenney temperature chambers held at -40 and at +60 °C (appendix A). The experimental curves (figure 1) show anomalously high and low thermal conductivity values measured for the transient tests near the temperature boundaries of -40 and +60 °C, as expected. The effects of the gas atmospheres on the global thermal conductivity values for the LCCM thermal battery package can be seen most clearly in the central portion of the heating/cooling curves where transient heating/cooling effects are minimized. Previously reported quasi-steadystate thermal conductivity values of two operating LCCM thermal batteries (KGP and KGQ) and of a copper-heat pellet stack LCCM heat transfer simulation (CUHP) are shown for comparison (1). For the CUHP experiment, the copper-heat pellet stack was heated pyrotechnically to ~500 °C using the heat pellets and then allowed to cool normally through the thermal insulation package in a fore pump vacuum operating atmosphere (1). Thermal conductivity values measured from the KGP cooling curves are almost identical to those measured from the CUHP cooling curves because the thermal insulation package was under a fore pump vacuum for both experiments. The GPS9Q LCCM thermal battery was sealed in dry room air at one atmosphere and then initiated. The GPS9Q thermal conductivity values (KGQ) measured from the cooling curves clearly show significant quantities of hydrogen gas in GPS9Q (1). The maximum GPS9Q gas pressure was nominally 10.7 abs atm (~1.08 MPa). Transient heating/cooling curves and thermal conductivity values for the copper-heat pellet stack experiment are also shown for a transient test done at temperatures above 60 °C in an atmosphere of pure hydrogen gas at 11 atmospheres absolute (11HYDCUST). Figure 2 shows selected data from figure 1 for the LCCM thermal insulation package global thermal conductivities for ultra pure carrier grade hydrogen at 1 and at 9 atmospheres absolute in the central temperature region of the experiment compared with those of air at 1 and at 7 atmospheres absolute.

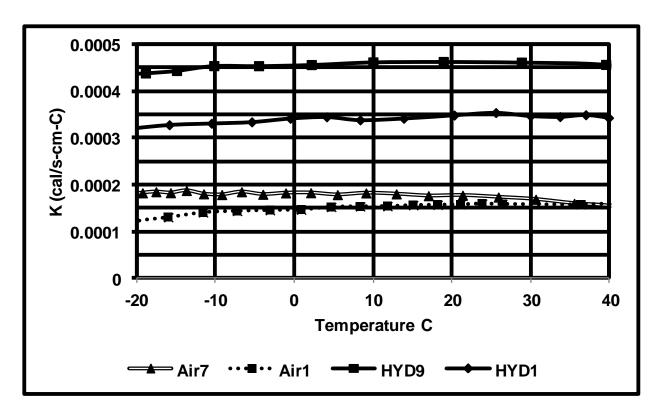


Figure 2. Measured global thermal conductivity values for the LCCM thermal insulation package in air at nominal pressures of 1 and 7 atmospheres absolute and in hydrogen at nominal pressures of 1 and 9 atmospheres absolute.

The data shown in figures 1 and 2 are intended to provide a rapid overview and facilitate an intuitive understanding of the significance of the experimental results. In appendix A, tests using additional gases are shown, and the test results are shown in more easily distinguishable graphical (and tabular) form for increased clarity and precision.

4. Hydrogen Removal by Oxidation with Barium Chromate

Oxidation of hydrogen gas using a mixture of oxidizing heat paper ash (ash from ~21/79 w/o Zr/BaCrO₄ heat powder) and pure BaCrO₄ was previously shown to be a highly effective method of removing hydrogen gas evolved from LCCM flight test heat paper (2). Subsequent experiments showed that BaCrO₄ was much more effective in removing H₂ than was the oxidizing heat paper ash.

The experiments were done in the previously reported (2) modified gas handling system, shown in figure 3. The modified gas handling system used filters and metering valves to prevent large gas flow rates and gross particulate redistribution that had caused failure of the bellows valves in the original gas handling system (2, 5). MV2 was the metering valve that connected the gas handling system with the BaCrO₄ experiments shown in figures 4 and 5. MV2 was closed during

pyrotechnic ignition and when opening BV7. The metering valves were designed to permit a low rate of gas flow when completely closed. The metering valves were all completely open for measurements of the equilibrium gas pressures (maximum pressures and final pressures) that permitted the measurements of the total quantities of gases present in the experiments of figures 4 and 5.

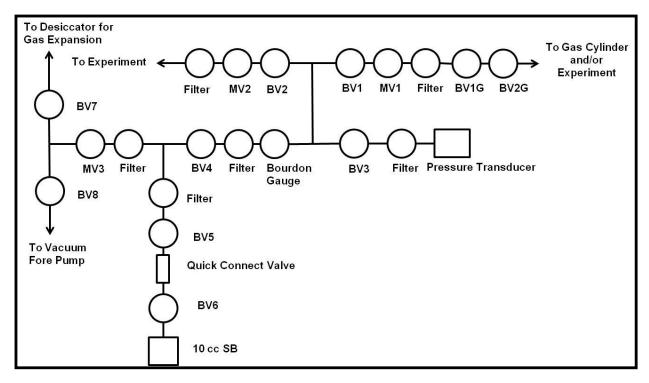


Figure 3. Modified gas handling system. The filters are 0.5μ .

Note: BV = bellows valve, MV = metering valve, SB = sample bottle.

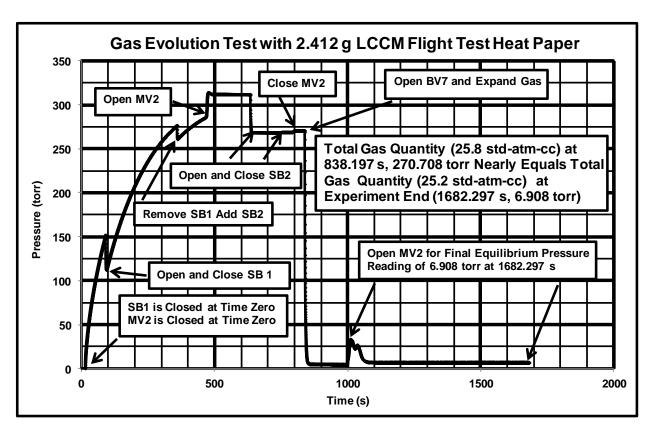


Figure 4. Gas evolution test for LCCM flight test heat paper. The constant pressures at ~314, ~270, and ~6.9 Torr with MV2 open strongly suggest that the ash is not reacting significantly with the gas at those pressures. The nearly equal gas volumes at ~314, ~270, and ~6.9 Torr, combined with the chromatographic analyses, show that little or no water vapor was formed during the experiment.

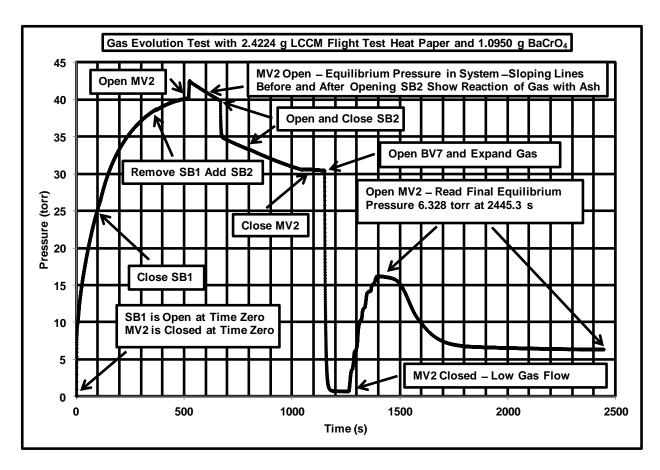


Figure 5. Gas evolution test for LCCM flight test heat paper in physical contact with barium chromate. Pressure decreases starting at ~42 and at ~35 Torr during the test show a reaction of the ash with the gas atmosphere.

LCCM used a common heat paper formulation made from 28/72 w/o Zr/BaCrO₄ heat powder, which forms a reducing ash that favors the formation of H₂ gas (2, 4). Pressure-time curves for tests with LCCM flight test heat paper only and with LCCM flight test heat paper in contact with pure BaCrO₄ are shown in figures 4 and 5.

The initial equilibrium gas pressures (maximum pressures) shown in figures 4 and 5 are produced by nearly identical masses of LCCM heat paper in the same test apparatus. Comparing figures 4 and 5, the initial equilibrium pressure developed by the heat paper gas evolution was therefore reduced from \sim 314 Torr to \sim 42 Torr by the oxidizing action of the pyrotechnically heated BaCrO₄. The gas in the figure 4 experiment contained no significant water vapor. The gas in the figure 5 experiment was saturated with water vapor at \sim 20 Torr (room temperature pressure of water vapor), so that the maximum equilibrium pressure of the gas that is not water vapor in figure 5 is approximately \sim (42–20)=22 Torr. This indicates an equilibrium pressure (and total gas quantity that is not water vapor) reduction to \sim 22x100/314 = 7.01% of the quantity of gas that would be present initially in the experiment of figure 5 immediately after opening MV2 if additional BaCrO₄ had not been added. The equilibrium pressures in the LCCM reducing ash test of figure 4 did not increase with time, so the ash did not evolve any significant quantities of

water vapor or other gases after the initial gas formed during ignition, even at the lengthy low pressure plateau near the end of the experiment. The equilibrium pressures in figure 5 were originally much less than those in figure 4, decreased noticeably for all times less than ~1050 s, and were still decreasing slightly at the end of the figure 5 experiment (2445.3 s). Neither test produced ash that increased the system gas pressure after the initial heat paper ignition, which is important, because increased gas pressures increases the global thermal conductivity of the thermal insulation package. The gas types and quantities evolved in the two tests are summarized in table 1 and shown on the basis of more complete analyses in appendix B.

The data in table 1 show that the sample of LCCM flight test heat paper used in the test of figure 4 evolved 10.71 std-atm-cc of gas per gram of heat paper, which was 82.4% hydrogen by volume of the first gas sample collected, and that no significant amount of water vapor was evolved. Assuming that the LCCM flight test heat paper in the figure 5 test in the absence of BaCrO₄ would also have evolved 10.71 std-atm-cc of gas/g of heat paper with the same hydrogen percentage, the hydrogen quantity in the figure 5 test has been reduced from an initial value of 10.71x0.824x2.4224=21.38 std-atm-cc to 0.4329x0.780x2.4224=0.8180 std-atm-cc by the end of the test. This amounts to 0.8180x100/21.38=3.826% of the original hydrogen value by the end of the experiment. Adding BaCrO₄ to the flight test heat paper therefore removed (21.38-0.8180)/ 1.095=18.78 std-atm-cc H₂/g of added BaCrO₄ by the end of the experiment (appendix B).

The total amount of gas at the end of the reducing ash experiment was 10.71x2.412=25.83 std-atm-cc and the total amount of gas at the end of the oxidizing ash experiment including the water vapor was 2.4224x(.4329+7.343)=18.84 std-atm-cc. Because one molecule of hydrogen gas is required to form one molecule of water vapor, the fact that these two total gas volumes are not approximately equal suggests that the oxidizing ash removed some water from the system completely. Any liquid water formed by the oxidizing ash in an operating thermal battery will initially form water vapor quantities determined by the temperature of the oxidizing ash.

Table 1. Oxidation of hydrogen gas evolved from LCCM heat paper using BaCrO₄.

Total Gas Evolved/g of Heat Paper (Excluding Water Vapor) std-atm-cc/g				
2.412 g Heat Paper		2.4224 g Heat Paper + 1.0950 g BaCrO ₄		
	10.71 0.4329			
	SB1 (SB2) Gas Volume Percentages			
H ₂	82.4 (72.7)	78.0 (60.5)		
O ₂	0.00 (2.13)	3.03 (6.71)		
N_2	0.00 (0.00)	6.76 (21.3)		
CO	16.2 (23.4)	12.3 (11.5)		
CH₄	1.44 (1.81)	0.00 (0.00)		
CO ₂	0.00 (0.00)	0.00 (0.00)		
Total	100.04 (100.04)	100.09 (100.01)		
A	Apparent Total Water Vapor Volume after Gas Expansion			
std-atm-cc/g of Heat Paper				
	0.00 7.343 (at 2445.3 s)			

5. Hydrogen Gas Gettering

Hydrogen gas gettering from atmospheres of pure hydrogen using Zr-based gas getters heated to $300\,^{\circ}$ C showed high getter reaction rates and capacities. Zr-based gas getters have been used for approximately 50 years and are well characterized for traditional getter applications. However, traditional gas getter applications typically remove gases from devices that are already at low pressures and are then required to hold the resulting significantly lower pressures in electronic devices or vacuum insulators over periods of months or years. A traditional getter might not be required to actually reach the desired low pressure for several days or weeks after the device is sealed. An American Society for Testing and Materials (ASTM) standard test to measure gas gettering rates and capacities for these getters (6) is done in the molecular flow region, at pressures not to exceed 5×10^{-4} Torr (6.7 x 10^{-2} Pa). Rapid removal of hydrogen gas at pressures of 1 atm or greater is not ordinarily required. Gas getter vendor representatives were optimistic that this getter could remove hydrogen gas from pressures of ~10 atm down to ~10 Torr or less within seconds but were not aware of any published data that could support their optimism.

The reaction of Zr-based getter materials with hydrogen is reversible and occurs most rapidly at $300\,^{\circ}$ C. At $300\,^{\circ}$ C, the Zr-based gas getter tested in this report has removed $136.8\,$ std-atm-cc of

hydrogen gas from a pure hydrogen atmosphere in ~10 s and demonstrated a gross hydrogen removal capacity of 175.1 std-atm-cc of hydrogen/g of getter material (5). At 700 °C, most hydrogen will be reversibly expelled from this gas getter material. Large quantities of hydrogen gas can be removed with this getter material at room temperature or below, but the getter reaction rates will be too slow to prolong most short-life munitions thermal battery lifetimes significantly. Because munitions thermal battery electrochemical cells typically operate at temperatures ranging from 600 to 330 °C and have outer case temperatures typically ranging from –40 to 300 °C during the operating lifetimes, the getter can be placed within the thermal insulation at some point where the temperature will be near 300 °C during normal battery operation for most practical applications.

Gas gettering tests done in pure hydrogen atmospheres are shown in figures 6 through 8. All four tests started with nominally 2 g of getter material at 300 °C under a fore pump vacuum of ~0.05 Torr (6.7 Pa). Measured hydrogen gas quantities ranging from 105.7 to 148.3 std-atm-cc of ultra pure carrier grade hydrogen gas at initial pressures ranging from nominally 7 to 10 atmospheres absolute were stored in the gas handling system and then allowed to enter the evacuated SS tube and react with nominally 2 g of Zr-based gas getter at 300 °C. For the four tests shown in figures 6 and 7, the hydrogen gas pressure would have been reduced to pressures ranging from nominally 3 to 5 atmospheres absolute by simple gas expansion if there had been no hydrogen removal action from the getter. The final atmospheric pressures for the experiments if no hydrogen had been removed, shown on the figures as P₀ values, were calculated using the measured system temperatures with the ideal gas law. These Po confirmation measurements implicitly used the 10-cc sample bottle as a volume reference standard for all of the gas handling system component volumes measured as explained in section 2. The P_o value calculated in this way for the test shown in figure 9 was confirmed experimentally to an accuracy of better than ±0.1% using a dual capacitance manometer to measure the gas pressure while the tube furnace heated the SS tube at 300 °C using helium as a test gas. The close agreement of calculation and experiment for the P_o gas pressure of figure 9 is particularly important because the gas quantities removed in that experiment were small. All of the gas gettering tests were done with the metering valves completely open (figure 3). The measured gas pressures for the gettering tests can therefore be used to determine the gas quantities present in real time throughout the course of all of the gas gettering tests.

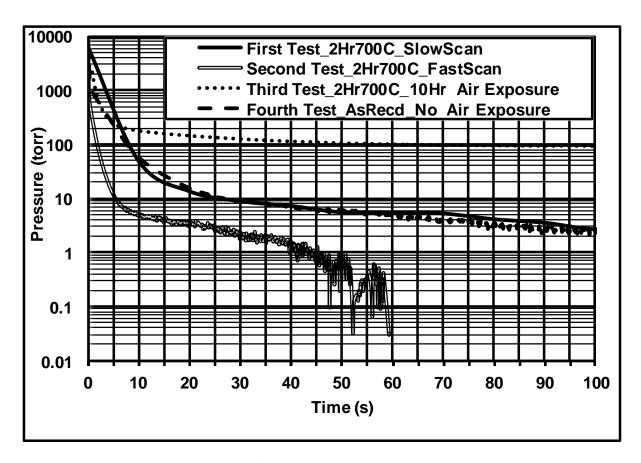


Figure 6. Gas getter tests in pure hydrogen (full pressure range).

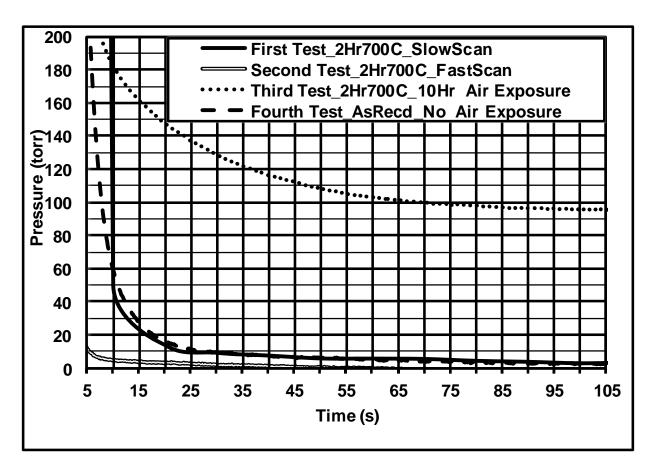


Figure 7. Gas getter tests in pure hydrogen (low pressure range).

The first test used 2.026 g of getter material that had been preheated under Ar for ~2 h at 700 °C and used a slow scan rate (1 reading each 10 s). The scan rate was then increased to 10 readings per second for the three subsequent tests. The second test was a repeat of the first test with the higher scan rate and used 2.082 g of getter. The third test used 1.992 g of getter that had been preheated under helium for ~2 h at 700 °C, cooled to room temperature, and then exposed to dry room air for ~10 h at a dew point of nominally -60 °C. The second and third tests were done to illustrate the effect of exposing the getter to dry room air under normal thermal battery construction conditions. The second and third tests used getter material taken from a larger initial single sample of 4.733 g that was split into two portions in an attempt to increase the initial uniformity of those samples. The fourth test used 2.029 g of getter as received (no 700 °C pretreatment under helium) and had been heated under a helium atmosphere to 300 °C ~2.5 h before the test. Measured gas pressures for all four tests are shown in figures 6 and 7. For the first test, time zero is a rough estimate because of the slow scan rate. For the three tests using a scan rate of 10 readings/s, time zero for the curves below was chosen from the data readouts ~0.1 s before the initial pressure in the gas handling system began to decrease as the hydrogen entered the evacuated SS tube containing the getter material at 300 °C.

Figure 7 is shown with the starting point changed to 5 s after the point of initial pressure decrease and with a reduced pressure range to illustrate more clearly the low gas pressure behavior produced after 5 s of exposure of hydrogen to the getter material. Although tests 2 and 4 appear substantially different in figures 7 and 8 because of the reduced pressure range, both tests removed more than 98.4% of the hydrogen gas originally present by 10 s after the original hydrogen exposure, and more than 99.9% of the hydrogen gas originally present by 60 s after the original hydrogen exposure, as confirmed by calculations for the fourth test shown in appendix C and summarized in figure 8.

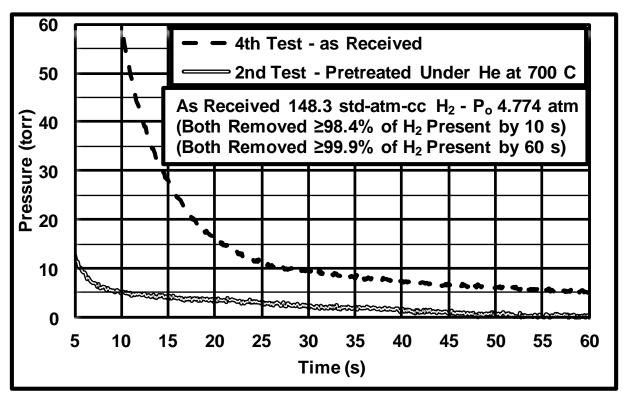


Figure 8. Gas getter tested in pure hydrogen as received and after 700 $^{\circ}$ C heating under helium (low pressure range).

The third test used getter material that had been exposed to dry room air for 10 h. Although the third test showed a significantly higher gas pressure, that gas getter material still removed 93.5% of the hydrogen (of 115.6 std-atm-cc originally present) by 10 s after the original exposure to hydrogen. That test shows that the getter could be exposed to dry room air using present thermal battery construction methods and still be effective.

Hydrogen gas gettering rates and capacities in hydrogen/air gas mixtures were reduced substantially from the rates in pure hydrogen atmospheres, but were still large enough to be potentially useful (figure 9). Gas chromatographic analyses at the end of the hydrogen/air experiments showed that all of the air had been removed and only hydrogen gas remained. An Excel sheet analysis of a hydrogen/air gas mixture test is shown in appendix C-2. The tests with

hydrogen/air mixtures illustrated the importance of reducing thermal battery gas evolution to very low levels if getter materials are to be used for hydrogen gas reduction.

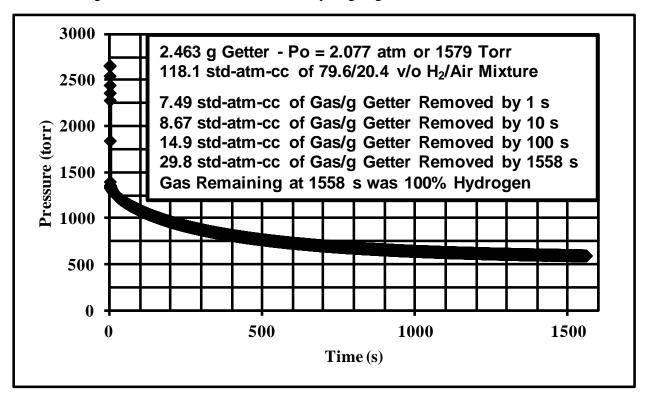


Figure 9. Gas gettering from a 79.6/20.4 volume percent hydrogen/air mixture.

Hydrogen gas gettering rates from H_2/Xe mixtures are expected to be rapid and will be confirmed in the near future. This is important because the batteries can be backfilled with chemically inert Xe gas during manufacture to reduce or eliminate O_2 and N_2 in the operating gas atmosphere and to reduce the global thermal conductivity of the thermal insulation package.

6. Thermal Modeling

The Fortran program used to calculate the global thermal conductivity values of the LCCM thermal insulation package shown in appendix A is an adaptation of a highly effective, thoroughly tested Fortran thermal battery heat transfer optimization program developed at ARL/Adelphi that has been reported previously (I). Most of the heat capacity data used have been reported to be accurate to better than $\pm 1\%$ (I, T). Uncertainties in geometric positions and temperature distributions within the battery generally limit the accuracy of the calculated lifetimes to $\pm 15\%$ in the absence of special effort. Fortran programs, supplemented by Excel spreadsheet analyses, remain a rapid and reliable method of thermal battery heat transfer optimization. Sierra finite element thermal battery heat transfer programs can greatly enhance the

rapid display of arbitrary internal temperature distributions and other operating parameters of the thermal battery electrochemical-heat-source stack and insulation package throughout the operating battery lifetimes.

7. Summary and Conclusions

The effect of hydrogen and other gases on the global thermal conductivity of LCCM thermal insulation packages was confirmed directly using transient heat transfer experiments. Graphical and tabular experimental values for the global thermal conductivity of the LCCM thermal insulation package are reported. The global thermal conductivity of thermal battery thermal insulation packages in controlled gas atmospheres can be measured easily and is a direct demonstration of the effectiveness of hydrogen removal methods.

BaCrO₄ placed in physical contact with LCCM heat paper reduced the hydrogen gas evolution quantity to ~7.01% of its original value early in the figure 5 experiment and to ~3.83% of its original value by the end of the figure 5 experiment. Previous experiments that did not use metering valve restrictions have shown low gas quantities similar to those measured in figure 5 immediately after heat paper ignition. The BaCrO₄ removed a total of 18.78 std-atm-cc of H₂ gas/g of BaCrO₄ by the end of the figure 5 experiment. By using Zr and BaCrO₄ of increased chemical purity in the heat paper, and by adding sufficient BaCrO₄, it should be possible to essentially eliminate hydrogen gas from operating thermal batteries. Any liquid water formed by this method of hydrogen oxidation will initially be present at the vapor pressure of water at the temperature of the oxidizing heat paper ash. If hydrogen gas could be removed completely from operating thermal battery atmospheres, it should be possible to increase munitions thermal reserve battery energy densities (reduce volumes) by factors ranging from 1.5 to 3. Significantly greater volumetric energy density improvement is possible if the batteries are backfilled with low thermal conductivity chemically inert gases such as Kr or Xe during manufacture. BaCrO₄ has the advantage that it is inexpensive, and that the hydrogen gas oxidizing ash formed is not present at all until the thermal battery pyrotechnic material is initiated, so there is no need to protect an active chemical surface during the required 20-year storage lifetime of the thermal battery. The possible presence and extent of chemical reactions that form hydrogen gas from water in thermal batteries that operate with higher case temperatures than LCCM must be evaluated before using this method of reducing hydrogen gas in the operating battery atmosphere.

Zr-based gas getters are highly effective in atmospheres of pure hydrogen, but were much less effective in mixtures of hydrogen and air. If Zr-based gas getters are to be used in practical applications, the presence of the other gases commonly found in thermal battery operating atmospheres (O₂, N₂, CO, CH₄, and CO₂) must also be minimized. Backfilling thermal batteries with chemically inert, low thermal conductivity gases such as Xe or Kr during manufacture could eliminate air from the operating atmosphere and improve gas getter performance by reducing the

global thermal conductivity of the thermal insulation package. Battery construction methods, materials selection, chemical processing, internal construction methods, and internal heat balancing can all be effective gas control methods. The use of pyrotechnic iron powders that yield small quantities of hydrogen gas and the choice of thermal insulators with minimal quantities of hydrogen gas evolution from binder materials and tape adhesives could be highly effective. If Zr-based gas getters were used, they would require some method of protecting the active getter surface during the required 20-year thermal battery storage lifetime.

The removal of hydrogen gas from various gas atmospheres is more easily studied independently from thermal battery operation. A number of factors arising from thermal battery operation can easily mask the effectiveness of gas removal techniques if battery electrical output is used as the sole criterion of success of the gas getter. Small internal modifications can produce large differences in the measured thermal lifetimes. A slight increase in the amounts of anodic or cathodic active electrochemical materials, a slight increase or decrease in electrochemical-heat-source cell stack length or diameter, a slight change in an internal local or global heat balance, or a slight change in the types and placement of adhesive tapes and thermal insulation binders can all produce large changes in the measured battery lifetimes for specific applications. This is especially true in munitions thermal batteries such as LCCM, where the thermal capacity of the thermal insulation package is large with respect to the thermal capacity of the electrochemical-heat-source stack. For LCCM, the initial transient heating effects of the thermal insulation can easily mask the effects of lower thermal conductivity of the thermal insulation package. For the effective study of thermal battery improvement using gas control methods, collaboration with a thermal battery vendor is suggested.

Placement of pyrotechnic material such that the insulation package is properly heated without overheating the thermal cells is crucial and the proper placement must be determined experimentally. If the internal pyrotechnic material is placed correctly during thermal battery construction, it should be possible to increase the electrical lifetimes of most presently fielded munitions thermal batteries by values inversely proportional to the reduction of the thermal conductivity values obtained by removing hydrogen gas. This means that the present volumetric energy density of LCCM could be improved by a factor of 3 (1, 2). Many thermal batteries have significantly longer lifetimes than LCCM and the effects of hydrogen gas removal in such batteries could be of proportionately greater significance and could be more easily demonstrated.

8. References

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- 6. ASTM F 798 97 (Reapproved 2002), "Standard Practice for Determining Gettering Rate, Sorption Capacity, and Gas Content of Nonevaporable Getters in the Molecular Flow Region," ASTM International, West Conshohocken PA (2003).
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Appendix A. Measured Global Thermal Conductivity Values for the LCCM Thermal Insulation Package

This appendix shows thermal modeling methods used for measurement of the global thermal conductivity of the LCCM thermal insulation package in various gas atmospheres. As explained in section 3 of the main report, convection and radiation heat loss rates are not significant. Total heat loss through the insulation package can be calculated using the conduction heat transfer equation $dq/dt = K*S*\Delta T$ where dq/dt = heat loss rate (cal/s), K = thermal conductivity (cal/s-cm-°C), S = thermal geometric shape factor (cm), and $\Delta T = thermal$ difference (°C) using the measured K values (1).

The LCCM thermal battery GPS9SU battery was used for most tests shown in this appendix and had been tested as a fully operating battery in the quasi-steady-state mode before the transient tests were started. The battery contained some sulfur in the insulation package in an unsuccessful attempt to remove hydrogen from the system through hydrogen sulfide formation. Measured thermal conductivity values for GPS9SU by this method agreed with those found for other LCCM thermal batteries and for the copper-heat pellet stack. The added sulfur is not believed to have affected the measured thermal conductivity values.

A-1. Fortran Input File Used to Calculate Global Thermal Conductivity "K" Values for the LCCM Thermal Insulation Package from Transient Heat Transfer Experiments

Below is the input data file hyd1csi that was used for the measurement of the global thermal conductivity of the thermal insulation package in the LCCM thermal battery GPS9SU when hydrogen is present at nominally one atmosphere in the thermal insulation package.

The experimental heating curve data shown below were obtained by removing the LCCM reusable test fixture containing the fully assembled LCCM thermal battery GPS9SU with attached thermocouples from a temperature chamber at –40 °C and placing it into a temperature chamber at +60 °C. The four columns from left to right are measured values of time (s), cell stack top temperature °C, cell stack bottom temperature °C, and case temperature °C.

0.	-38.659	-38.536	-38.576
29.996	-38.39	-38.135	-37.521
50.014	-37.837	-37.893	-36.006
100.026	-36.956	-37.25	-32.069
150.012	-36.053	-36.525	-28.137
200.015	-34.705	-35.3	-24.307
300.012	-30.711	-31.561	-17.295
400.012	-25.798	-26.816	-10.984
500.023	-20.466	-21.564	-5.207
599.996	-15.184	-16.15	-0.192
700.008	-9.958	-10.883	4.619
800.009	-4.831	-5.741	8.976
900.029	0.03	-0.829	13.054

999.996	4.497	3.658	16.604
1199.996	12.442	11.746	22.681
1400.023	19.119	18.597	27.475
1599.996	24.657	24.186	31.428
1800.025	29.162	28.742	34.955
2000.011	33.032	32.606	38.012
2199.996	36.415	36.022	40.776
2400.	39.324	39.035	43.286
2600.011	41.854	41.679	45.528
2799.996	44.189	44.069	47.58
3000.018	46.263	46.202	49.337
3199.996	48.139	48.12	50.915
3399.996	49.734	49.756	52.244
3600.017	51.159	51.186	53.361
3799.996	52.533	52.479	54.377
4000.017	53.696	53.606	55.194
4199.999	54.699	54.599	55.892
4400.025	55.574	55.432	56.57
4599.996	56.288	56.176	57.104
4799.996	56.972	56.834	57.601
5000.013	57.526	57.386	58.006
5400.009	58.467	58.332	58.735
5800.019	59.137	58.995	59.244
6400.022	59.806	59.651	59.794
6800.005	60.165	60.04	60.085
9409.996	61.007	60.874	60.688

A-2. Fortran Source File Used to Calculate Global Thermal Conductivity "K" Values for the LCCM Thermal Insulation Package from Transient Heat Transfer Experiments

The text below is the Fortran program su09.for used to calculate the global thermal conductivity "K" values of the LCCM thermal insulation package from the heating curve shown in section A-1. The Fortran program has numerous comment statements for first time users. The Fortran program was written, compiled, and executed in Unix, using a Linux machine, with the help of the ARL "zteam." Additional program details are available on request.

```
11 = LiCl(1)
C 1 = Fe
            6 = LiF(s)
                                        16 = Al(1)
C 2= FeO
                          12= S (rhombic) 17= Heat Pellet
            7 = LiF(1)
C = KCl(s) = LiBr(s)
                                         18= Anode
                          13 = Li(s)
C 4 = \text{FeS}2 9 = \text{LiBr}(1) 14 = \text{Li}(1)
                                         19= Elec-Cathode
C 5 = MgO
            10=LiCl(s) 15=Al(s)
                                          20= Eutectic
C
    PR1= Weight fraction Fe, FeO, KCl in burned heat pellet.
C
    PR2= Weight fraction LiF, LiBr, LiCl, Li, Al, in anode.
    PR3= Weight fraction Fe, FeS2, MgO, LiF, LiBr, LiCl, in
    electrolyte/cathode.
C
    GMW= Gram molecular weights of first 16 substances.
C
    703.15 K = 430 C = Melting point of LiF-LiBr-LiCl eutectic.
C
    453.7 \text{ K} = 180.55 \text{ C} = \text{Melting point of Lithium}.
C
    932 K = 658.85 C = Melting point of Aluminum.
C
    70.20 cal/g = Heat of fusion of LiF-LiBr-LiCl eutectic.
C
     17.5326 cal/g = Heat of fusion of LiF-LiBr-KBr eutectic in
C
        electrolyte-cathode (70.20*(.0238872+.170860+.0550045)
        = 17.5326).
```

```
C 7.02 cal/g = Heat of fusion of LiF-LiBr-LiCl eutectic in
```

- C anode (70.2*(.00956438+.0684120+.0220237)=7.02) (Li(Al)).
- C The experimental cathode uses 45/55 E/B and anode uses only E.
- C The separator uses 53/47 E/B. The E/C composition was
- C calculated using 53/47 E/B for both separators and cathodes.
- C All heat capacities calculated as sum of component
- C heat capacities.
- C Liquid lithium heat capacity used above 453.7 K.
- C Liquid aluminum heat capacity used above 932 K.
- C Heat of fusion of lithium 715/6.94 = 103.026 c/g is ignored.
- C Heat of fusion of aluminum 2570/26.98 = 95.2557 c/g is ignored.
- C T(K) = T(C) + 273.15
- C The sulfur heat capacity used (K. K. Kelley) is for rhombic
- C sulfur (sulfur at a temperature below 95.45 C)

DOUBLE PRECISION COND

DIMENSION PR1(16),PR2(16),PR3(16),GMW(16),DELH(21)

```
DATA
```

1 PR1/0.595687,0.318222,0.0861032,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.

1 0.,0.,0./,

2 PR2/0.,0.,0.,0.,0.,00956438,0.,.0684120,0.,.0220237,0.,

3 0.,0.18,0.,0.72,0./,

4 PR3/0.0132193,0.,0.,0.515552,0.221478,.0238872,0.,.170860,0.,

5 .0550045,0.,0.,0.,0.,0.,0.,0.,

6 GMW/55.85,68.89,74.56,119.98,40.32,25.94,25.94,86.85,86.85,

7 42.39,42.39,32.07,6.94,6.94,26.98,26.98/

OPEN(UNIT=5,NAME='/home/fkrieger/fk/vk/hyd1csi',TYPE='OLD')
OPEN(UNIT=6,NAME='/home/fkrieger/fk/vk/qfile',TYPE='NEW')

READ(5,111) TI1,TT1,TB1,TCA1

8 READ(5,111,END=219) TI2,TT2,TB2,TCA2

111 FORMAT(F15.8,F15.8,F15.8,F15.8)

IF (((TT2+TB2)/2.).GT.((TT1+TB1)/2.)) THEN

THIGH=(TT2+TB2)/2.

TLOW=(TT1+TB1)/2.

ELSE

THIGH=(TT1+TB1)/2.

TLOW = (TT2 + TB2)/2.

END IF

TCASE=0.5*(TCA1+TCA2)

TIME= TI2-TI1

TM=(THIGH+TLOW)/2.

TIN=(TM+TCASE)/2.

T1=TLOW+273.15

T2=THIGH+273.15

DO I=1,5

IF((T2-T1).EQ.0.) GO TO 19

DELH(I)=ENTG(T1,T2,I)/GMW(I)/(T2-T1)

END DO

DELH(12) = ENTG(T1,T2,12)/GMW(12)/(T2-T1)

IF(T2.LT.703.15) THEN

```
DELH(6) = ENTG(T1,T2,6)/GMW(6)/(T2-T1)
       DELH(8) = ENTG(T1,T2,8)/GMW(8)/(T2-T1)
       DELH(10) = ENTG(T1,T2,10)/GMW(10)/(T2-T1)
      ELSE IF(T1.GT.703.15) THEN
       DELH(6) = ENTG(T1,T2,7)/GMW(7)/(T2-T1)
       DELH(8) = ENTG(T1,T2,9)/GMW(9)/(T2-T1)
       DELH(10) = ENTG(T1,T2,11)/GMW(11)/(T2-T1)
      ELSE
       DELH(6) = ENTG(T1,703.15,6)/GMW(6)/(T2-T1)
  1
            + ENTG(703.15,T2,7)/GMW(7)/(T2-T1)
       DELH(8) = ENTG(T1,703.15,8)/GMW(8)/(T2-T1)
  1
            + ENTG(703.15,T2,9)/GMW(9)/(T2-T1)
       DELH(10) = ENTG(T1,703.15,10)/GMW(10)/(T2-T1)
  1
            + ENTG(703.15,T2,11)/GMW(11)/(T2-T1)
      END IF
      IF(T2.LT.453.7) THEN
       DELH(13)= ENTG(T1,T2,13)/GMW(13)/(T2-T1)
      ELSE IF(T1.GT.453.7) THEN
       DELH(13) = ENTG(T1,T2,14)/GMW(14)/(T2-T1)
       DELH(13)= ENTG(T1,453.7,13)/GMW(13)/(T2-T1)
  1
            + ENTG(453.7,T2,14)/GMW(14)/(T2-T1)
      END IF
      IF(T2.LT.932.0) THEN
       DELH(15)= ENTG(T1,T2,15)/GMW(15)/(T2-T1)
      ELSE IF(T1.GT.932.0) THEN
       DELH(15) = ENTG(T1,T2,16)/GMW(16)/(T2-T1)
       DELH(15) = ENTG(T1.932.0.15)/GMW(15)/(T2-T1)
  1
            + ENTG(932.0,T2,16)/GMW(16)/(T2-T1)
      END IF
   DELH(17)=0.0
   DELH(18)=0.0
   DELH(19)=0.0
   DO J=1,16
    DELH(17)=DELH(J)*PR1(J)+DELH(17)
    DELH(18)=DELH(J)*PR2(J)+DELH(18)
    DELH(19)=DELH(J)*PR3(J)+DELH(19)
   END DO
   DELH(20)=.0956438*DELH(6)+.684120*DELH(8)+.220237*DELH(10)
   CPHPAP = 0.14
   CPINS = .1716+.00009867*(TIN+273.15)
C Expansion of the battery stack components with temperature.
   XPANST=1.+(TM-22.)*.1118E-4+.53E-8*(TM-22.)**2
   XPANCA=1.+(TCASE-22.)*.1118E-4+.53E-8*(TCASE-22.)**2
  FL1=.8075*2.54*XPANST
   FL2=1.1992*2.54*XPANCA
   D1=0.75*2.54*XPANST
   D2=1.243*2.54*XPANCA
   PI=3.1415927
   RWX=PI*(D1**2/(FL2-FL1)+1.08*D1)
   RWY=PI*2.*FL1/ALOG(D2/D1)
   SHP=RWX+RWY
```

```
XHC = (THIGH-TLOW)*((7.403*DELH(17))
  1+2.390*DELH(18))+6.112*DELH(19)+2.759*DELH(1)+
  1(CPHPAP*5.055+CPINS*7.426+2.349*DELH(1)
  1+0.615*DELH(12))*.5)
  IF(THIGH.GT.430.1.AND.TLOW.LT.429.9) THEN
  TEUTFUS=7.02*2.402+17.5326*5.982
  XHC=XHC+TEUTFUS
  ELSE
  TEUTFUS=0.0
  END IF
  AVTI = (TI1+TI2)/2.
  COND= XHC/(SHP*TIME*ABS(TCASE-TM))
  DELTHT= COND*SHP*ABS(TCASE-TM)
  TSTSTHC = 2.759*(T2-T1)*DELH(1)
  TINSTHC = 2.349*.5*(T2-T1)*DELH(1)
  THPHC = 7.403*(T2-T1)*DELH(17)
  TAHC = 2.390*(T2-T1)*DELH(18)
  TECHC = 6.112*(T2-T1)*DELH(19)
  TPAPHC = 5.055*(T2-T1)*.5*CPHPAP
  TINSHC = 7.426*(T2-T1)*.5*CPINS
  TSUHC = 0.615*(T2-T1)*DELH(12)
  WRITE(6,220) THIGH, TLOW, DELH(1)
  WRITE(6,221) DELH(2), DELH(3), DELH(4)
  WRITE(6,222) DELH(5), DELH(13), DELH(15)
  WRITE(6,223) DELH(6), DELH(8), DELH(10)
  WRITE(6,224) DELH(17), DELH(18), DELH(19)
  WRITE(6,225) DELH(20), DELH(12), XHC
  WRITE(6,231) CPINS, CPHPAP
  WRITE(6,250) TSTSTHC, THPHC, TSUHC
  WRITE(6,251) TECHC, TINSHC, TINSTHC
  WRITE(6,252) TAHC, TPAPHC
  WRITE(6,235) T1,T2,TEUTFUS
  WRITE(6,232) COND,TM,TIN
  WRITE(6,233) TI1,TI2,TIME
  WRITE(6,237) TCA1,TCA2,TCASE
  WRITE(6,236) DELTHT, AVTI
  WRITE(6,242) XHC,XPANST,XPANCA
  WRITE(6,243) RWX,RWY,SHP
19 TI1=TI2
  TT1=TT2
  TB1=TB2
  TCA1=TCA2
  GO TO 8
219 WRITE(6,226)
  WRITE(6,227)
  WRITE(6,228)
  WRITE(6,229)
  WRITE(6,230)
220 FORMAT('THIGH=',F9.4,'TLOW=',F9.4,'Fe=',F12.7)
221 FORMAT('FeO=',F12.7,'KCl=',F12.7,'FeS2=',F12.7)
```

```
222 FORMAT('MgO=',F12.7,'Li=',F12.7,'Al=',F12.7)
223 FORMAT('LiF=', F12.7, 'LiBr=', F12.7, 'LiCl=', F12.7)
224 FORMAT('HPHC=', F12.7,' AHC=',F12.7,' ECHC=', F12.7)
225 FORMAT('EUT=',F12.7, 'SHC=',F12.7, 'XHC=',F15.5)
226 FORMAT('HFUSEC = 17.5326 HFUSA = 7.02 HFUSEUT = 70.2')
227 FORMAT('ECMASS = 6.112 ANODEMASS = 2.390')
228 FORMAT('HPELLETMASS = 7.403 STEELSTACKMASS = 2.759')
229 FORMAT('INSMASS = 7.426 HEAT PAPER MASS = 5.056')
230 FORMAT('SULFUR MASS = 0.615 MASS STEEL IN INS = 2.349')
231 FORMAT('CPINS=',F12.7, 'CPHPAP=', F12.4)
232 FORMAT(' K=' ,D18.10,' TAVSTACK= ' ,F8.3,' TAVINS= ' ,F8.3)
233 FORMAT('TIME1=',F12.5, 'TIME2=',F12.5, 'INTTIME=',F12.5)
235 FORMAT('T1=',F12.6, 'T2=',F12.6, 'TEUTFUS=',F12.6//)
236 FORMAT('DELTHT=',F12.6, 'AVTIME=',F12.6)
237 FORMAT('TICASE=',F10.4,'TFCASE=',F10.4,'TCASE=',F10.4)
242 FORMAT('XHC=',F12.6,' XPANST=',F12.8,'XPANCA=',F12.8)
243 FORMAT('RWX=',F12.6,'RWY=',F12.6,'SHP=',F12.6//)
250 FORMAT('TSTSTHC=',F12.6, 'THPHC=',F12.6, 'TSHC=',F12.6)
251 FORMAT('TECHC=',F12.6,' TINSHC=',F12.6, 'TINSTHC=',F12.6)
252 FORMAT('TAHC=',F12.6, 'TPAPHC=',F12.6)
999 CONTINUE
  END
  FUNCTION ENTG(T1,T2,J)
  This function calculates the molar heat content between T1 and T2.
  TR1, TR2, TR3 are molar heat capacity coefficients of the first
  16 substances.
  DIMENSION TR1(16),TR2(16),TR3(16)
  DATA
  2 TR1/3.04, 11.66, 9.89, 17.88, 10.18, 10.41, 15.50, 11.50,
      16.00, 11.00, 16.00, 3.58, 1.64, 6.78, 4.94, 7.00/,
  4 TR2/ 0.00758, 0.002, 0.0052, 0.00132, .00174, 0.00390, 0.,
      0.00302, 0., .0034, 0., .00624, .0111, 0., .00296, 0./,
  6 TR3/60000., -67000., 77000., -305000., -148000., -138000., 0.,
      0., 0., 0., 0., 84000., 99000., 0., 0./
  ENTG=(T2-T1)*TR1(J)+.5*(T2*T2-T1*T1)*TR2(J)-(1./T2-1./T1)*TR3(J)
  RETURN
  END
```

A-3. Fortran Output File – Global Thermal Conductivity "K" Values for the LCCM Thermal Insulation Package Calculated from Transient Heat Transfer Experiments

The text below is the output file hyd1cso from the source program su09.for using the input file hyd1csi. Both heating and cooling curves may be used with the Fortran program. The thermal conductivity "K" is the global thermal conductivity of the thermal insulation package in cal/s–cm–°C and is always calculated as a positive value. More significant figures are included than are experimentally justifiable to facilitate debugging of the Fortran source program. Data shown in addition to the "K" values can be used to facilitate additional calculations using other mathematical models.

THIGH= -38.2625 TLOW= -38.5975 Fe= 0.1057873
FeO= 0.1584169 KCl= 0.1677595 FeS2= 0.1054665
MgO= 0.1959849 Li= 0.8314196 Al= 0.2088500
LiF= 0.3400390 LiBr= 0.1405740 LiCl= 0.2783215
HPHC= 0.1278725 AHC= 0.3190264 ECHC= 0.1466282
EUT= 0.1899888 SHC= 0.1573013 XHC= 1.38921
CPINS= 0.1947786 CPHPAP= 0.1400
TSTSTHC= 0.097777 THPHC= 0.317131 TSHC= 0.032409
TECHC= 0.300230 TINSHC= 0.242281 TINSTHC= 0.041624
TAHC= 0.255434 TPAPHC= 0.118542
T1= 234.552490 T2= 234.887497 TEUTFUS= 0.0000000

K= 0.2797025489E-02 TAVSTACK= -38.430 TAVINS= -38.239 TIME1= 0.00000 TIME2= 29.99600 INTTIME= 29.99600 TICASE= -38.5760 TFCASE= -37.5210 TCASE= -38.0485 DELTHT= 0.046313 AVTIME= 14.998000 XHC= 1.389208 XPANST= 0.99934375 XPANCA= 0.99934781 RWX= 17.910761 RWY= 25.491518 SHP= 43.402279

THIGH= -37.8650 TLOW= -38.2625 Fe= 0.1057761
FeO= 0.1584829 KCl= 0.1677264 FeS2= 0.1056151
MgO= 0.1962095 Li= 0.8313189 Al= 0.2088903
LiF= 0.3403969 LiBr= 0.1405868 LiCl= 0.2783510
HPHC= 0.1278840 AHC= 0.3190422 ECHC= 0.1467668
EUT= 0.1900383 SHC= 0.1573728 XHC= 1.64885
CPINS= 0.1948601 CPHPAP= 0.1400
TSTSTHC= 0.116002 THPHC= 0.376315 TSHC= 0.038471
TECHC= 0.356565 TINSHC= 0.287591 TINSTHC= 0.049382
TAHC= 0.303092 TPAPHC= 0.140652
T1= 234.887497 T2= 235.284988 TEUTFUS= 0.0000000

K= 0.1459579216E-02 TAVSTACK= -38.064 TAVINS= -37.414 TIME1= 29.99600 TIME2= 50.01400 INTTIME= 20.01800 TICASE= -37.5210 TFCASE= -36.0060 TCASE= -36.7635 DELTHT= 0.082368 AVTIME= 40.005001 XHC= 1.648851 XPANST= 0.99934763 XPANCA= 0.99936134 RWX= 17.910492 RWY= 25.491129 SHP= 43.401619

THIGH= -37.1030 TLOW= -37.8650 Fe= 0.1057599
FeO= 0.1585851 KCl= 0.1676759 FeS2= 0.1058447
MgO= 0.1965568 Li= 0.8311779 Al= 0.2089535
LiF= 0.3409509 LiBr= 0.1406069 LiCl= 0.2783972
HPHC= 0.1279025 AHC= 0.3190701 ECHC= 0.1469811
EUT= 0.1901152 SHC= 0.1574850 XHC= 3.16245
CPINS= 0.1950232 CPHPAP= 0.1400
TSTSTHC= 0.222348 THPHC= 0.721517 TSHC= 0.073803
TECHC= 0.684549 TINSHC= 0.551787 TINSTHC= 0.094653
TAHC= 0.581091 TPAPHC= 0.269637
T1= 235.284988 T2= 236.046997 TEUTFUS= 0.000000

K= 0.4227481259E-03 TAVSTACK= -37.484 TAVINS= -35.761 TIME1= 50.01400 TIME2= 100.02600 INTTIME= 50.01200

TICASE= -36.0060 TFCASE= -32.0690 TCASE= -34.0375 DELTHT= 0.063234 AVTIME = 75.020004 XHC= 3.162451 XPANST= 0.99935377 XPANCA= 0.99939013 RWX= 17.909811 RWY= 25.490143 SHP= 43.399956

THIGH= -36.2890 TLOW= -37.1030 Fe= 0.1057380 FeO= 0.1587250 KCl= 0.1676068 FeS2= 0.1061591 MgO= 0.1970323 Li= 0.8309860 Al= 0.2090402 LiF= 0.3417094 LiBr= 0.1406343 LiCl= 0.2784606 HPHC= 0.1279280 AHC= 0.3191085 ECHC= 0.1472745 EUT= 0.1902205 SHC= 0.1576387 XHC= 3.38061 CPINS= 0.1952562 CPHPAP= 0.1400 TSTSTHC= 0.237468 THPHC= 0.770895 TSHC= 0.078915 TECHC= 0.732711 TINSHC= 0.590135 TINSTHC= 0.101089 TAHC= 0.620809 TPAPHC= 0.288032 T1= 236.046997 T2= 236.860992 TEUTFUS= 0.0000000

K= 0.2363742533E-03 TAVSTACK= -36.696 TAVINS= -33.399 TIME1= 100.02600 TIME2= 150.01199 INTTIME= 49.98599 TICASE= -32.0690 TFCASE= -28.1370 TCASE= -30.1030 DELTHT= 0.067631 AVTIME = 125.018997 XHC= 3.380614 XPANST= 0.99936199 XPANCA= 0.99943185 RWX= 17.908779 RWY= 25.488657 SHP= 43.397438

THIGH= -35.0025 TLOW= -36.2890 Fe= 0.1057111
FeO= 0.1589088 KCl= 0.1675172 FeS2= 0.1065714
MgO= 0.1976563 Li= 0.8307571 Al= 0.2091554
LiF= 0.3427059 LiBr= 0.1406709 LiCl= 0.2785448
HPHC= 0.1279628 AHC= 0.3191641 ECHC= 0.1476596
EUT= 0.1903593 SHC= 0.1578430 XHC= 5.34759
CPINS= 0.1954995 CPHPAP= 0.1400
TSTSTHC= 0.375216 THPHC= 1.218711 TSHC= 0.124885
TECHC= 1.161059 TINSHC= 0.933856 TINSTHC= 0.159729
TAHC= 0.981344 TPAPHC= 0.455228
T1= 236.860992 T2= 238.147491 TEUTFUS= 0.0000000

K= 0.2615139820E-03 TAVSTACK= -35.646 TAVINS= -30.934 TIME1= 150.01199 TIME2= 200.01500 INTTIME= 50.00301 TICASE= -28.1370 TFCASE= -24.3070 TCASE= -26.2220 DELTHT= 0.106945 AVTIME= 175.013489 XHC= 5.347587 XPANST= 0.99937308 XPANCA= 0.99947321 RWX= 17.907919 RWY= 25.487413 SHP= 43.395332

THIGH= -31.1360 TLOW= -35.0025 Fe= 0.1056553
FeO= 0.1593508 KCl= 0.1673071 FeS2= 0.1075595
MgO= 0.1991532 Li= 0.8303093 Al= 0.2094381
LiF= 0.3451017 LiBr= 0.1407605 LiCl= 0.2787515
HPHC= 0.1280521 AHC= 0.3193206 ECHC= 0.1485837
EUT= 0.1906953 SHC= 0.1583444 XHC= 16.10312
CPINS= 0.1958940 CPHPAP= 0.1400
TSTSTHC= 1.127097 THPHC= 3.665325 TSHC= 0.376527
TECHC= 3.511338 TINSHC= 2.812317 TINSTHC= 0.479802

TAHC= 2.950822 TPAPHC= 1.368161 T1= 238.147491 T2= 242.013992 TEUTFUS= 0.000000

K= 0.3024905454E-03 TAVSTACK= -33.069 TAVINS= -26.935 TIME1= 200.01500 TIME2= 300.01199 INTTIME= 99.99699 TICASE= -24.3070 TFCASE= -17.2950 TCASE= -20.8010 DELTHT= 0.161036 AVTIME = 250.013489 XHC= 16.103125 XPANST= 0.99940044 XPANCA= 0.99953121 RWX= 17.907333 RWY= 25.486565 SHP= 43.393898

THIGH= -26.3070 TLOW= -31.1360 Fe= 0.1055887
FeO= 0.1600714 KCl= 0.1669790 FeS2= 0.1091611
MgO= 0.2015844 Li= 0.8298644 Al= 0.2099151
LiF= 0.3490070 LiBr= 0.1409116 LiCl= 0.2791002
HPHC= 0.1282135 AHC= 0.3196394 ECHC= 0.1500853
EUT= 0.1912490 SHC= 0.1591903 XHC= 20.17523
CPINS= 0.1964372 CPHPAP= 0.1400
TSTSTHC= 1.406779 THPHC= 4.583509 TSHC= 0.472768
TECHC= 4.429739 TINSHC= 3.522130 TINSTHC= 0.598862
TAHC= 3.689053 TPAPHC= 1.708740
T1= 242.013992 T2= 246.842987 TEUTFUS= 0.0000000

K= 0.3188412229E-03 TAVSTACK= -28.722 TAVINS= -21.431 TIME1= 300.01199 TIME2= 400.01199 INTTIME= 100.00000 TICASE= -17.2950 TFCASE= -10.9840 TCASE= -14.1395 DELTHT= 0.201752 AVTIME= 350.011993 XHC= 20.175228 XPANST= 0.99944657 XPANCA= 0.99960285 RWX= 17.907267 RWY= 25.486454 SHP= 43.393723

THIGH= -21.0150 TLOW= -26.3070 Fe= 0.1055536
FeO= 0.1608718 KCl= 0.1666380 FeS2= 0.1109249
MgO= 0.2042692 Li= 0.8298254 Al= 0.2104702
LiF= 0.3533425 LiBr= 0.1410876 LiCl= 0.2795061
HPHC= 0.1284180 AHC= 0.3200945 ECHC= 0.1517447
EUT= 0.1918735 SHC= 0.1601750 XHC= 22.18868
CPINS= 0.1969850 CPHPAP= 0.1400
TSTSTHC= 1.541151 THPHC= 5.030996 TSHC= 0.521303
TECHC= 4.908144 TINSHC= 3.870602 TINSTHC= 0.656065
TAHC= 4.048523 TPAPHC= 1.872577
T1= 246.842987 T2= 252.134995 TEUTFUS= 0.0000000

K= 0.3284581762E-03 TAVSTACK= -23.661 TAVINS= -15.878 TIME1= 400.01199 TIME2= 500.02301 INTTIME= 100.01102 TICASE= -10.9840 TFCASE= -5.2070 TCASE= -8.0955 DELTHT= 0.221862 AVTIME = 450.017517 XHC= 22.188679 XPANST= 0.99950051 XPANCA= 0.99966836 RWX= 17.907827 RWY= 25.487249 SHP= 43.395077

THIGH= -15.6670 TLOW= -21.0150 Fe= 0.1055625 FeO= 0.1616720 KCl= 0.1663235 FeS2= 0.1126712 MgO= 0.2069359 Li= 0.8302990 Al= 0.2110540 LiF= 0.3576746 LiBr= 0.1412726 LiCl= 0.2799328 HPHC= 0.1286508 AHC= 0.3206635 ECHC= 0.1533943 EUT= 0.1925083 SHC= 0.1612102 XHC= 22.50628 CPINS= 0.1975137 CPHPAP= 0.1400 TSTSTHC= 1.557590 THPHC= 5.093450 TSHC= 0.530224 TECHC= 5.014003 TINSHC= 3.922059 TINSTHC= 0.663063 TAHC= 4.098637 TPAPHC= 1.892392 T1= 252.134995 T2= 257.483002 TEUTFUS= 0.000000

K= 0.3316490911E-03 TAVSTACK= -18.341 TAVINS= -10.520 TIME1= 500.02301 TIME2= 599.99597 INTTIME= 99.97296 TICASE= -5.2070 TFCASE= -0.1920 TCASE= -2.6995 DELTHT= 0.225124 AVTIME = 550.009521 XHC= 22.506275 XPANST= 0.99955761 XPANCA= 0.99972707 RWX= 17.908794 RWY= 25.488623 SHP= 43.397415

THIGH= -10.4205 TLOW= -15.6670 Fe= 0.1056141
FeO= 0.1624299 KCl= 0.1660514 FeS2= 0.1143084
MgO= 0.2094444 Li= 0.8312530 Al= 0.2116351
LiF= 0.3617753 LiBr= 0.1414568 LiCl= 0.2803577
HPHC= 0.1288992 AHC= 0.3213148 ECHC= 0.1549474
EUT= 0.1931201 SHC= 0.1622408 XHC= 22.15929
CPINS= 0.1980174 CPHPAP= 0.1400
TSTSTHC= 1.528771 THPHC= 5.006417 TSHC= 0.523485
TECHC= 4.968630 TINSHC= 3.857422 TINSTHC= 0.650794
TAHC= 4.029003 TPAPHC= 1.856471
T1= 257.483002 T2= 262.729492 TEUTFUS= 0.0000000

K= 0.3346076701E-03 TAVSTACK= -13.044 TAVINS= -5.415 TIME1= 599.99597 TIME2= 700.00800 INTTIME= 100.01202 TICASE= -0.1920 TFCASE= 4.6190 TCASE= 2.2135 DELTHT= 0.221566 AVTIME = 650.001953 XHC= 22.159290 XPANST= 0.99961472 XPANCA= 0.99978089 RWX= 17.909933 RWY= 25.490244 SHP= 43.400177

THIGH= -5.2860 TLOW= -10.4205 Fe= 0.1057030
FeO= 0.1631378 KCl= 0.1658217 FeS2= 0.1158219
MgO= 0.2117714 Li= 0.8326204 Al= 0.2122045
LiF= 0.3656035 LiBr= 0.1416373 LiCl= 0.2807740
HPHC= 0.1291577 AHC= 0.3220291 ECHC= 0.1563895
EUT= 0.1937014 SHC= 0.1632508 XHC= 21.76267
CPINS= 0.1984996 CPHPAP= 0.1400
TSTSTHC= 1.497396 THPHC= 4.909368 TSHC= 0.515499
TECHC= 4.907815 TINSHC= 3.784269 TINSTHC= 0.637438
TAHC= 3.951759 TPAPHC= 1.816840
T1= 262.729492 T2= 267.863983 TEUTFUS= 0.0000000

K= 0.3422372101E-03 TAVSTACK= -7.853 TAVINS= -0.528 TIME1= 700.00800 TIME2= 800.00897 INTTIME= 100.00098 TICASE= 4.6190 TFCASE= 8.9760 TCASE= 6.7975 DELTHT= 0.217625 AVTIME = 750.008484 XHC= 21.762672 XPANST= 0.99967092 XPANCA= 0.99983126 THIGH= -0.3995 TLOW= -5.2860 Fe= 0.1058222
FeO= 0.1637910 KCl= 0.1656320 FeS2= 0.1172042
MgO= 0.2139039 Li= 0.8343146 Al= 0.2127542
LiF= 0.3691342 LiBr= 0.1418115 LiCl= 0.2811759
HPHC= 0.1294202 AHC= 0.3227844 ECHC= 0.1577122
EUT= 0.1942468 SHC= 0.1642256 XHC= 20.78135
CPINS= 0.1989549 CPHPAP= 0.1400
TSTSTHC= 1.426680 THPHC= 4.681750 TSHC= 0.493531
TECHC= 4.710282 TINSHC= 3.609757 TINSTHC= 0.607334
TAHC= 3.769717 TPAPHC= 1.729090
T1= 267.863983 T2= 272.750488 TEUTFUS= 0.0000000

K= 0.3454162215E-03 TAVSTACK= -2.843 TAVINS= 4.086 TIME1= 800.00897 TIME2= 900.02899 INTTIME= 100.02002 TICASE= 8.9760 TFCASE= 13.0540 TCASE= 11.0150 DELTHT= 0.207772 AVTIME = 850.018982 XHC= 20.781355 XPANST= 0.99972552 XPANCA= 0.99987787 RWX= 17.912405 RWY= 25.493769 SHP= 43.406174

THIGH= 4.0775 TLOW= -0.3995 Fe= 0.1059610
FeO= 0.1643766 KCl= 0.1654812 FeS2= 0.1184309
MgO= 0.2158029 Li= 0.8362083 Al= 0.2132679
LiF= 0.3722977 LiBr= 0.1419743 LiCl= 0.2815514
HPHC= 0.1296763 AHC= 0.3235447 ECHC= 0.1588911
EUT= 0.1947435 SHC= 0.1651367 XHC= 19.09938
CPINS= 0.1993740 CPHPAP= 0.1400
TSTSTHC= 1.308841 THPHC= 4.297910 TSHC= 0.454682
TECHC= 4.347825 TINSHC= 3.314229 TINSTHC= 0.557171
TAHC= 3.461954 TPAPHC= 1.584194
T1= 272.750488 T2= 277.227509 TEUTFUS= 0.0000000

K= 0.3388223995E-03 TAVSTACK= 1.839 TAVINS= 8.334 TIME1= 900.02899 TIME2= 999.99597 INTTIME= 99.96698 TICASE= 13.0540 TFCASE= 16.6040 TCASE= 14.8290 DELTHT= 0.191057 AVTIME = 950.012451 XHC= 19.099379 XPANST= 0.99977672 XPANCA= 0.99992013 RWX= 17.913633 RWY= 25.495527 SHP= 43.409161

THIGH= 12.0940 TLOW= 4.0775 Fe= 0.1061865
FeO= 0.1651212 KCl= 0.1653186 FeS2= 0.1199720
MgO= 0.2181986 Li= 0.8391882 Al= 0.2139532
LiF= 0.3763182 LiBr= 0.1421915 LiCl= 0.2820524
HPHC= 0.1300336 AHC= 0.3246389 ECHC= 0.1603799
EUT= 0.1953869 SHC= 0.1663520 XHC= 34.34074
CPINS= 0.1999197 CPHPAP= 0.1400
TSTSTHC= 2.348577 THPHC= 7.716972 TSHC= 0.820138
TECHC= 7.858089 TINSHC= 5.950647 TINSTHC= 0.999784
TAHC= 6.219882 TPAPHC= 2.836631
T1= 277.227509 T2= 285.243988 TEUTFUS= 0.0000000

K= 0.3422312730E-03 TAVSTACK= 8.086 TAVINS= 13.864 TIME1= 999.99597 TIME2= 1199.99597 INTTIME= 200.00000 TICASE= 16.6040 TFCASE= 22.6810 TCASE= 19.6425 DELTHT= 0.171704 AVTIME = 1099.995972 XHC= 34.340736 XPANST= 0.99984545 XPANCA= 0.99997365 RWX= 17.915398 RWY= 25.498045 SHP= 43.413445

THIGH= 18.8580 TLOW= 12.0940 Fe= 0.1065019
FeO= 0.1659583 KCl= 0.1651730 FeS2= 0.1216806
MgO= 0.2208671 Li= 0.8432612 Al= 0.2147640
LiF= 0.3808346 LiBr= 0.1424485 LiCl= 0.2826452
HPHC= 0.1304753 AHC= 0.3260296 ECHC= 0.1620403
EUT= 0.1961253 SHC= 0.1677901 XHC= 29.11585
CPINS= 0.2005524 CPHPAP= 0.1400
TSTSTHC= 1.987527 THPHC= 6.533413 TSHC= 0.697984
TECHC= 6.699008 TINSHC= 5.036827 TINSTHC= 0.846086
TAHC= 5.270588 TPAPHC= 2.393444
T1= 285.243988 T2= 292.007996 TEUTFUS= 0.0000000

K= 0.3491414827E-03 TAVSTACK= 15.476 TAVINS= 20.277 TIME1= 1199.99597 TIME2= 1400.02295 INTTIME= 200.02698 TICASE= 22.6810 TFCASE= 27.4750 TCASE= 25.0780 DELTHT= 0.145560 AVTIME = 1300.009521 XHC= 29.115850 XPANST= 0.99992728 XPANCA= 1.00003445 RWX= 17.917603 RWY= 25.501194 SHP= 43.418797

THIGH= 24.4215 TLOW= 18.8580 Fe= 0.1068040
FeO= 0.1666210 KCl= 0.1650892 FeS2= 0.1230128
MgO= 0.2229588 Li= 0.8470985 Al= 0.2154402
LiF= 0.3844073 LiBr= 0.1426628 LiCl= 0.2831395
HPHC= 0.1308589 AHC= 0.3272669 ECHC= 0.1633435
EUT= 0.1967224 SHC= 0.1689893 XHC= 24.04424
CPINS= 0.2010723 CPHPAP= 0.1400
TSTSTHC= 1.639411 THPHC= 5.389639 TSHC= 0.578206
TECHC= 5.554359 TINSHC= 4.153611 TINSTHC= 0.697894
TAHC= 4.351597 TPAPHC= 1.968647
T1= 292.007996 T2= 297.571503 TEUTFUS= 0.0000000

K= 0.3544598585E-03 TAVSTACK= 21.640 TAVINS= 25.546 TIME1= 1400.02295 TIME2= 1599.99597 INTTIME= 199.97302 TICASE= 27.4750 TFCASE= 31.4280 TCASE= 29.4515 DELTHT= 0.120237 AVTIME = 1500.009521 XHC= 24.044237 XPANST= 0.99999595 XPANCA= 1.00008357 RWX= 17.919518 RWY= 25.503929 SHP= 43.423447

THIGH= 28.9520 TLOW= 24.4215 Fe= 0.1070760 FeO= 0.1671415 KCl= 0.1650441 FeS2= 0.1240458 MgO= 0.2245880 Li= 0.8505173 Al= 0.2159940 LiF= 0.3872117 LiBr= 0.1428383 LiCl= 0.2835443 HPHC= 0.1311827 AHC= 0.3283288 ECHC= 0.1643598 EUT= 0.1971999 SHC= 0.1699713 XHC= 19.64383 CPINS= 0.2015058 CPHPAP= 0.1400 TSTSTHC= 1.338408 THPHC= 4.399761 TSHC= 0.473583 TECHC= 4.551178 TINSHC= 3.389670 TINSTHC= 0.569757 TAHC= 3.555100 TPAPHC= 1.603113 T1= 297.571503 T2= 302.101990 TEUTFUS= 0.0000000

K= 0.3476491547E-03 TAVSTACK= 26.687 TAVINS= 29.939 TIME1= 1599.99597 TIME2= 1800.02502 INTTIME= 200.02905 TICASE= 31.4280 TFCASE= 34.9550 TCASE= 33.1915 DELTHT= 0.098205 AVTIME = 1700.010498 XHC= 19.643827 XPANST= 1.00005257 XPANCA= 1.00012589 RWX= 17.921036 RWY= 25.506096 SHP= 43.427132

THIGH= 32.8190 TLOW= 28.9520 Fe= 0.1073179
FeO= 0.1675603 KCl= 0.1650217 FeS2= 0.1248680
MgO= 0.2258897 Li= 0.8535382 Al= 0.2164546
LiF= 0.3894671 LiBr= 0.1429843 LiCl= 0.2838811
HPHC= 0.1314581 AHC= 0.3292432 ECHC= 0.1651725
EUT= 0.1975897 SHC= 0.1707883 XHC= 16.81247
CPINS= 0.2018754 CPHPAP= 0.1400
TSTSTHC= 1.144982 THPHC= 3.763309 TSHC= 0.406170
TECHC= 3.903874 TINSHC= 2.898564 TINSTHC= 0.487416
TAHC= 3.042912 TPAPHC= 1.368339
T1= 302.101990 T2= 305.968994 TEUTFUS= 0.0000000

K= 0.3457869752E-03 TAVSTACK= 30.885 TAVINS= 33.685 TIME1= 1800.02502 TIME2= 2000.01099 INTTIME= 199.98596 TICASE= 34.9550 TFCASE= 38.0120 TCASE= 36.4835 DELTHT= 0.084068 AVTIME = 1900.018066 XHC= 16.812468 XPANST= 1.00009978 XPANCA= 1.00016296 RWX= 17.922235 RWY= 25.507814 SHP= 43.430050

THIGH= 36.2185 TLOW= 32.8190 Fe= 0.1075380
FeO= 0.1679129 KCl= 0.1650126 FeS2= 0.1255540
MgO= 0.2269793 Li= 0.8562734 Al= 0.2168532
LiF= 0.3913652 LiBr= 0.1431106 LiCl= 0.2841725
HPHC= 0.1317006 AHC= 0.3300557 ECHC= 0.1658534
EUT= 0.1979218 SHC= 0.1714953 XHC= 14.81452
CPINS= 0.2021982 CPHPAP= 0.1400
TSTSTHC= 1.008624 THPHC= 3.314450 TSHC= 0.358544
TECHC= 3.446064 TINSHC= 2.552219 TINSTHC= 0.429369
TAHC= 2.681643 TPAPHC= 1.202915
T1= 305.968994 T2= 309.368500 TEUTFUS= 0.000000

K= 0.3498468723E-03 TAVSTACK= 34.519 TAVINS= 36.956 TIME1= 2000.01099 TIME2= 2199.99609 INTTIME= 199.98511 TICASE= 38.0120 TFCASE= 40.7760 TCASE= 39.3940 DELTHT= 0.074078 AVTIME = 2100.003418 XHC= 14.814524 XPANST= 1.00014079 XPANCA= 1.00019598 RWX= 17.923250 RWY= 25.509268 SHP= 43.432518 THIGH= 39.1795 TLOW= 36.2185 Fe= 0.1077386
FeO= 0.1682145 KCl= 0.1650123 FeS2= 0.1261359
MgO= 0.2279063 Li= 0.8587570 Al= 0.2172022
LiF= 0.3929881 LiBr= 0.1432213 LiCl= 0.2844277
HPHC= 0.1319161 AHC= 0.3307827 ECHC= 0.1664331
EUT= 0.1982089 SHC= 0.1721142 XHC= 12.93004
CPINS= 0.2024852 CPHPAP= 0.1400
TSTSTHC= 0.880159 THPHC= 2.891637 TSHC= 0.313422
TECHC= 3.012043 TINSHC= 2.226160 TINSTHC= 0.374682
TAHC= 2.340879 TPAPHC= 1.047749
T1= 309.368500 T2= 312.329498 TEUTFUS= 0.0000000

K= 0.3435873368E-03 TAVSTACK= 37.699 TAVINS= 39.865 TIME1= 2199.99609 TIME2= 2400.00000 INTTIME= 200.00391 TICASE= 40.7760 TFCASE= 43.2860 TCASE= 42.0310 DELTHT= 0.064649 AVTIME = 2299.998047 XHC= 12.930037 XPANST= 1.00017679 XPANCA= 1.00022614 RWX= 17.924105 RWY= 25.510477 SHP= 43.434582

THIGH= 41.7665 TLOW= 39.1795 Fe= 0.1079190
FeO= 0.1684724 KCl= 0.1650174 FeS2= 0.1266299
MgO= 0.2286953 Li= 0.8609849 Al= 0.2175064
LiF= 0.3943751 LiBr= 0.1433177 LiCl= 0.2846501
HPHC= 0.1321061 AHC= 0.3314276 ECHC= 0.1669267
EUT= 0.1984565 SHC= 0.1726537 XHC= 11.31700
CPINS= 0.2027393 CPHPAP= 0.1400
TSTSTHC= 0.770277 THPHC= 2.530043 TSHC= 0.274694
TECHC= 2.639408 TINSHC= 1.947423 TINSTHC= 0.327905
TAHC= 2.049198 TPAPHC= 0.915412
T1= 312.329498 T2= 314.916504 TEUTFUS= 0.0000000

K= 0.3311234468E-03 TAVSTACK= 40.473 TAVINS= 42.440 TIME1= 2400.00000 TIME2= 2600.01099 INTTIME= 200.01099 TICASE= 43.2860 TFCASE= 45.5280 TCASE= 44.4070 DELTHT= 0.056582 AVTIME = 2500.005371 XHC= 11.316997 XPANST= 1.00020826 XPANCA= 1.00025308 RWX= 17.924828 RWY= 25.511511 SHP= 43.436340

THIGH= 44.1290 TLOW= 41.7665 Fe= 0.1080846
FeO= 0.1686984 KCl= 0.1650262 FeS2= 0.1270603
MgO= 0.2293842 Li= 0.8630244 Al= 0.2177780
LiF= 0.3955908 LiBr= 0.1434038 LiCl= 0.2848486
HPHC= 0.1322774 AHC= 0.3320121 ECHC= 0.1673580
EUT= 0.1986754 SHC= 0.1731354 XHC= 10.35129
CPINS= 0.2029673 CPHPAP= 0.1400
TSTSTHC= 0.704507 THPHC= 2.313465 TSHC= 0.251554
TECHC= 2.416571 TINSHC= 1.780412 TINSTHC= 0.299907
TAHC= 1.874655 TPAPHC= 0.835966
T1= 314.916504 T2= 317.278992 TEUTFUS= 0.0000000

K= 0.3304246347E-03 TAVSTACK= 42.948 TAVINS= 44.751 TIME1= 2600.01099 TIME2= 2799.99609 INTTIME= 199.98511 TICASE= 45.5280 TFCASE= 47.5800 TCASE= 46.5540 DELTHT= 0.051760 AVTIME = 2700.003418 XHC= 10.351294 XPANST= 1.00023663 XPANCA= 1.00027776 RWX= 17.925463 RWY= 25.512419 SHP= 43.437881

THIGH= 46.2325 TLOW= 44.1290 Fe= 0.1082373
FeO= 0.1688993 KCl= 0.1650375 FeS2= 0.1274405
MgO= 0.2299941 Li= 0.8649021 Al= 0.2180229
LiF= 0.3966708 LiBr= 0.1434814 LiCl= 0.2850277
HPHC= 0.1324333 AHC= 0.3325460 ECHC= 0.1677400
EUT= 0.1988712 SHC= 0.1735698 XHC= 9.22967
CPINS= 0.2031714 CPHPAP= 0.1400
TSTSTHC= 0.628166 THPHC= 2.062294 TSHC= 0.224541
TECHC= 2.156581 TINSHC= 1.586841 TINSTHC= 0.267409
TAHC= 1.671843 TPAPHC= 0.744329
T1= 317.278992 T2= 319.382507 TEUTFUS= 0.0000000

K= 0.3240774968E-03 TAVSTACK= 45.181 TAVINS= 46.820 TIME1= 2799.99609 TIME2= 3000.01807 INTTIME= 200.02197 TICASE= 47.5800 TFCASE= 49.3370 TCASE= 48.4585 DELTHT= 0.046143 AVTIME = 2900.007080 XHC= 9.229666 XPANST= 1.00026202 XPANCA= 1.00029945 RWX= 17.926046 RWY= 25.513256 SHP= 43.439301

THIGH= 48.1295 TLOW= 46.2325 Fe= 0.1083768
FeO= 0.1690770 KCl= 0.1650500 FeS2= 0.1277751
MgO= 0.2305318 Li= 0.8666144 Al= 0.2182425
LiF= 0.3976257 LiBr= 0.1435510 LiCl= 0.2851882
HPHC= 0.1325740 AHC= 0.3330297 ECHC= 0.1680770
EUT= 0.1990455 SHC= 0.1739591 XHC= 8.33422
CPINS= 0.2033523 CPHPAP= 0.1400
TSTSTHC= 0.567217 THPHC= 1.861775 TSHC= 0.202947
TECHC= 1.948734 TINSHC= 1.432304 TINSTHC= 0.241463
TAHC= 1.509879 TPAPHC= 0.671244
T1= 319.382507 T2= 321.279480 TEUTFUS= 0.0000000

K= 0.3257629287E-03 TAVSTACK= 47.181 TAVINS= 48.653 TIME1= 3000.01807 TIME2= 3199.99609 INTTIME= 199.97803 TICASE= 49.3370 TFCASE= 50.9150 TCASE= 50.1260 DELTHT= 0.041676 AVTIME = 3100.007080 XHC= 8.334223 XPANST= 1.00028491 XPANCA= 1.00031865 RWX= 17.926588 RWY= 25.514021 SHP= 43.440609

THIGH= 49.7450 TLOW= 48.1295 Fe= 0.1085009
FeO= 0.1692310 KCl= 0.1650628 FeS2= 0.1280640
MgO= 0.2309967 Li= 0.8681360 Al= 0.2184349
LiF= 0.3984536 LiBr= 0.1436120 LiCl= 0.2853289
HPHC= 0.1326981 AHC= 0.3334574 ECHC= 0.1683685
EUT= 0.1991974 SHC= 0.1743004 XHC= 7.10541
CPINS= 0.2035107 CPHPAP= 0.1400
TSTSTHC= 0.483609 THPHC= 1.587018 TSHC= 0.173174
TECHC= 1.662469 TINSHC= 1.220736 TINSTHC= 0.205871

TAHC= 1.287501 TPAPHC= 0.571648 T1= 321.279480 T2= 322.894989 TEUTFUS= 0.000000

K= 0.3095124266E-03 TAVSTACK= 48.937 TAVINS= 50.258 TIME1= 3199.99609 TIME2= 3399.99609 INTTIME= 200.00000 TICASE= 50.9150 TFCASE= 52.2440 TCASE= 51.5795 DELTHT= 0.035527 AVTIME = 3299.996094 XHC= 7.105405 XPANST= 1.00030494 XPANCA= 1.00033534 RWX= 17.927065 RWY= 25.514704 SHP= 43.441769

THIGH= 51.1725 TLOW= 49.7450 Fe= 0.1086108
FeO= 0.1693632 KCl= 0.1650759 FeS2= 0.1283105
MgO= 0.2313942 Li= 0.8694816 Al= 0.2186022
LiF= 0.3991636 LiBr= 0.1436650 LiCl= 0.2854512
HPHC= 0.1328067 AHC= 0.3338331 ECHC= 0.1686178
EUT= 0.1993285 SHC= 0.1745971 XHC= 6.28459
CPINS= 0.2036461 CPHPAP= 0.1400
TSTSTHC= 0.427767 THPHC= 1.403493 TSHC= 0.153283
TECHC= 1.471192 TINSHC= 1.079403 TINSTHC= 0.182099
TAHC= 1.138963 TPAPHC= 0.505128
T1= 322.894989 T2= 324.322510 TEUTFUS= 0.0000000

K= 0.3085833450E-03 TAVSTACK= 50.459 TAVINS= 51.631 TIME1= 3399.99609 TIME2= 3600.01709 INTTIME= 200.02100 TICASE= 52.2440 TFCASE= 53.3610 TCASE= 52.8025 DELTHT= 0.031420 AVTIME = 3500.006592 XHC= 6.284587 XPANST= 1.00032246 XPANCA= 1.00034940 RWX= 17.927500 RWY= 25.515326 SHP= 43.442825

THIGH= 52.5060 TLOW= 51.1725 Fe= 0.1087109
FeO= 0.1694820 KCl= 0.1650884 FeS2= 0.1285315
MgO= 0.2317509 Li= 0.8707055 Al= 0.2187534
LiF= 0.3998016 LiBr= 0.1437129 LiCl= 0.2855617
HPHC= 0.1329052 AHC= 0.3341741 ECHC= 0.1688416
EUT= 0.1994467 SHC= 0.1748653 XHC= 5.87587
CPINS= 0.2037668 CPHPAP= 0.1400
TSTSTHC= 0.399960 THPHC= 1.312023 TSHC= 0.143407
TECHC= 1.376114 TINSHC= 1.008905 TINSTHC= 0.170262
TAHC= 1.065032 TPAPHC= 0.471858
T1= 324.322510 T2= 325.656006 TEUTFUS= 0.0000000

K= 0.3332094930E-03 TAVSTACK= 51.839 TAVINS= 52.854 TIME1= 3600.01709 TIME2= 3799.99609 INTTIME= 199.97900 TICASE= 53.3610 TFCASE= 54.3770 TCASE= 53.8690 DELTHT= 0.029382 AVTIME = 3700.006592 XHC= 5.875873 XPANST= 1.00033832 XPANCA= 1.00036168 RWX= 17.927906 RWY= 25.515905 SHP= 43.443810

THIGH= 53.6510 TLOW= 52.5060 Fe= 0.1088019 FeO= 0.1695878 KCl= 0.1651006 FeS2= 0.1287277 MgO= 0.2320682 Li= 0.8718180 Al= 0.2188894 LiF= 0.4003701 LiBr= 0.1437560 LiCl= 0.2856611 HPHC= 0.1329941 AHC= 0.3344828 ECHC= 0.1690406 EUT= 0.1995524 SHC= 0.1751064 XHC= 5.04922 CPINS= 0.2038732 CPHPAP= 0.1400 TSTSTHC= 0.343708 THPHC= 1.127305 TSHC= 0.123304 TECHC= 1.182975 TINSHC= 0.866735 TINSTHC= 0.146316 TAHC= 0.915320 TPAPHC= 0.405154 T1= 325.656006 T2= 326.800995 TEUTFUS= 0.0000000

K= 0.3403904266E-03 TAVSTACK= 53.078 TAVINS= 53.932 TIME1= 3799.99609 TIME2= 4000.01709 INTTIME= 200.02100 TICASE= 54.3770 TFCASE= 55.1940 TCASE= 54.7855 DELTHT= 0.025243 AVTIME = 3900.006592 XHC= 5.049217 XPANST= 1.00035262 XPANCA= 1.00037229 RWX= 17.928297 RWY= 25.516462 SHP= 43.444759

THIGH= 54.6490 TLOW= 53.6510 Fe= 0.1088818
FeO= 0.1696786 KCl= 0.1651122 FeS2= 0.1288953
MgO= 0.2323394 Li= 0.8727936 Al= 0.2190071
LiF= 0.4008575 LiBr= 0.1437933 LiCl= 0.2857472
HPHC= 0.1330716 AHC= 0.3347524 ECHC= 0.1692109
EUT= 0.1996436 SHC= 0.1753153 XHC= 4.40395
CPINS= 0.2039634 CPHPAP= 0.1400
TSTSTHC= 0.299809 THPHC= 0.983175 TSHC= 0.107605
TECHC= 1.032166 TINSHC= 0.755814 TINSTHC= 0.127628
TAHC= 0.798471 TPAPHC= 0.353148
T1= 326.800995 T2= 327.799011 TEUTFUS= 0.0000000

K= 0.3638773633E-03 TAVSTACK= 54.150 TAVINS= 54.847 TIME1= 4000.01709 TIME2= 4199.99902 INTTIME= 199.98193 TICASE= 55.1940 TFCASE= 55.8920 TCASE= 55.5430 DELTHT= 0.022022 AVTIME = 4100.007812 XHC= 4.403946 XPANST= 1.00036490 XPANCA= 1.00038099 RWX= 17.928640 RWY= 25.516954 SHP= 43.445595

THIGH= 55.5030 TLOW= 54.6490 Fe= 0.1089499
FeO= 0.1697567 KCl= 0.1651218 FeS2= 0.1290398
MgO= 0.2325731 Li= 0.8736264 Al= 0.2191081
LiF= 0.4012771 LiBr= 0.1438254 LiCl= 0.2858211
HPHC= 0.1331379 AHC= 0.3349828 ECHC= 0.1693576
EUT= 0.1997218 SHC= 0.1754944 XHC= 3.77067
CPINS= 0.2040430 CPHPAP= 0.1400
TSTSTHC= 0.256698 THPHC= 0.841693 TSHC= 0.092169
TECHC= 0.883959 TINSHC= 0.646980 TINSTHC= 0.109276
TAHC= 0.683699 TPAPHC= 0.302178
T1= 327.799011 T2= 328.652985 TEUTFUS= 0.0000000

K= 0.3756626102E-03 TAVSTACK= 55.076 TAVINS= 55.653 TIME1= 4199.99902 TIME2= 4400.02490 INTTIME= 200.02588 TICASE= 55.8920 TFCASE= 56.5700 TCASE= 56.2310 DELTHT= 0.018851 AVTIME = 4300.011719 XHC= 3.770670 XPANST= 1.00037563 XPANCA= 1.00038886 THIGH= 56.2320 TLOW= 55.5030 Fe= 0.1090103
FeO= 0.1698229 KCl= 0.1651315 FeS2= 0.1291613
MgO= 0.2327703 Li= 0.8743626 Al= 0.2191955
LiF= 0.4016328 LiBr= 0.1438530 LiCl= 0.2858849
HPHC= 0.1331958 AHC= 0.3351849 ECHC= 0.1694815
EUT= 0.1997888 SHC= 0.1756493 XHC= 3.22038
CPINS= 0.2041120 CPHPAP= 0.1400
TSTSTHC= 0.219255 THPHC= 0.718833 TSHC= 0.078750
TECHC= 0.755154 TINSHC= 0.552489 TINSTHC= 0.093336
TAHC= 0.583999 TPAPHC= 0.257958
T1= 328.652985 T2= 329.381989 TEUTFUS= 0.0000000

K= 0.3823267471E-03 TAVSTACK= 55.868 TAVINS= 56.352 TIME1= 4400.02490 TIME2= 4599.99609 INTTIME= 199.97119 TICASE= 56.5700 TFCASE= 57.1040 TCASE= 56.8370 DELTHT= 0.016104 AVTIME = 4500.010742 XHC= 3.220382 XPANST= 1.00038469 XPANCA= 1.00039589 RWX= 17.929165 RWY= 25.517702 SHP= 43.446869

THIGH= 56.9030 TLOW= 56.2320 Fe= 0.1090632
FeO= 0.1698815 KCl= 0.1651398 FeS2= 0.1292689
MgO= 0.2329448 Li= 0.8750083 Al= 0.2192724
LiF= 0.4019472 LiBr= 0.1438774 LiCl= 0.2859412
HPHC= 0.1332467 AHC= 0.3353624 ECHC= 0.1695911
EUT= 0.1998480 SHC= 0.1757857 XHC= 2.96548
CPINS= 0.2041720 CPHPAP= 0.1400
TSTSTHC= 0.201905 THPHC= 0.661881 TSHC= 0.072540
TECHC= 0.695508 TINSHC= 0.508671 TINSTHC= 0.085950
TAHC= 0.537809 TPAPHC= 0.237430
T1= 329.381989 T2= 330.052979 TEUTFUS= 0.0000000

K= 0.4347392241E-03 TAVSTACK= 56.567 TAVINS= 56.960 TIME1= 4599.99609 TIME2= 4799.99609 INTTIME= 200.00000 TICASE= 57.1040 TFCASE= 57.6010 TCASE= 57.3525 DELTHT= 0.014827 AVTIME = 4699.996094 XHC= 2.965475 XPANST= 1.00039279 XPANCA= 1.00040197 RWX= 17.929382 RWY= 25.518015 SHP= 43.447395

THIGH= 57.4560 TLOW= 56.9030 Fe= 0.1091096
FeO= 0.1699324 KCl= 0.1651473 FeS2= 0.1293622
MgO= 0.2330961 Li= 0.8755739 Al= 0.2193395
LiF= 0.4022203 LiBr= 0.1438987 LiCl= 0.2859902
HPHC= 0.1332911 AHC= 0.3355177 ECHC= 0.1696861
EUT= 0.1998995 SHC= 0.1759047 XHC= 2.44491
CPINS= 0.2042244 CPHPAP= 0.1400
TSTSTHC= 0.166474 THPHC= 0.545684 TSHC= 0.059825
TECHC= 0.573538 TINSHC= 0.419339 TINSTHC= 0.070868
TAHC= 0.443451 TPAPHC= 0.195682
T1= 330.052979 T2= 330.605988 TEUTFUS= 0.0000000

K= 0.4508614657E-03 TAVSTACK= 57.180 TAVINS= 57.492 TIME1= 4799.99609 TIME2= 5000.01318 INTTIME= 200.01709 TICASE= 57.6010 TFCASE= 58.0060 TCASE= 57.8035 DELTHT= 0.012224 AVTIME = 4900.004883 XHC= 2.444914 XPANST= 1.00039983 XPANCA= 1.00040710 RWX= 17.929575 RWY= 25.518290 SHP= 43.447865

THIGH= 58.3995 TLOW= 57.4560 Fe= 0.1091665
FeO= 0.1699943 KCl= 0.1651566 FeS2= 0.1294755
MgO= 0.2332802 Li= 0.8762671 Al= 0.2194213
LiF= 0.4025525 LiBr= 0.1439246 LiCl= 0.2860501
HPHC= 0.1333455 AHC= 0.3357077 ECHC= 0.1698017
EUT= 0.1999622 SHC= 0.1760499 XHC= 4.17332
CPINS= 0.2042893 CPHPAP= 0.1400
TSTSTHC= 0.284177 THPHC= 0.931394 TSHC= 0.102155
TECHC= 0.979203 TINSHC= 0.715678 TINSTHC= 0.120973
TAHC= 0.757019 TPAPHC= 0.333862
T1= 330.605988 T2= 331.549500 TEUTFUS= 0.0000000

K= 0.5423685652E-03 TAVSTACK= 57.928 TAVINS= 58.149 TIME1= 5000.01318 TIME2= 5400.00879 INTTIME= 399.99561 TICASE= 58.0060 TFCASE= 58.7350 TCASE= 58.3705 DELTHT= 0.010433 AVTIME = 5200.010742 XHC= 4.173316 XPANST= 1.00040841 XPANCA= 1.00041366 RWX= 17.929800 RWY= 25.518612 SHP= 43.448410

THIGH= 59.0660 TLOW= 58.3995 Fe= 0.1092286
FeO= 0.1700609 KCl= 0.1651673 FeS2= 0.1295971
MgO= 0.2334778 Li= 0.8770243 Al= 0.2195101
LiF= 0.4029099 LiBr= 0.1439527 LiCl= 0.2861149
HPHC= 0.1334046 AHC= 0.3359146 ECHC= 0.1699259
EUT= 0.2000299 SHC= 0.1762073 XHC= 2.94961
CPINS= 0.2043595 CPHPAP= 0.1400
TSTSTHC= 0.200859 THPHC= 0.658236 TSHC= 0.072227
TECHC= 0.692223 TINSHC= 0.505734 TINSTHC= 0.085505
TAHC= 0.535093 TPAPHC= 0.235842
T1= 331.549500 T2= 332.216003 TEUTFUS= 0.000000

K= 0.6609963020E-03 TAVSTACK= 58.733 TAVINS= 58.861 TIME1= 5400.00879 TIME2= 5800.01904 INTTIME= 400.01025 TICASE= 58.7350 TFCASE= 59.2440 TCASE= 58.9895 DELTHT= 0.007374 AVTIME = 5600.013672 XHC= 2.949606 XPANST= 1.00041783 XPANCA= 1.00042081 RWX= 17.930048 RWY= 25.518970 SHP= 43.449020

THIGH= 59.7285 TLOW= 59.0660 Fe= 0.1092788 FeO= 0.1701151 KCl= 0.1651757 FeS2= 0.1296963 MgO= 0.2336389 Li= 0.8776357 Al= 0.2195821 LiF= 0.4032010 LiBr= 0.1439755 LiCl= 0.2861675 HPHC= 0.1334525 AHC= 0.3360820 ECHC= 0.1700271 EUT= 0.2000849 SHC= 0.1763349 XHC= 2.93309 CPINS= 0.2044185 CPHPAP= 0.1400 TSTSTHC= 0.199737 THPHC= 0.654492 TSHC= 0.071843 TECHC= 0.688448 TINSHC= 0.502823 TINSTHC= 0.085027 TAHC= 0.532124 TPAPHC= 0.234417 T1= 332.216003 T2= 332.878479 TEUTFUS= 0.000000

K= 0.9241293883E-03 TAVSTACK= 59.397 TAVINS= 59.458 TIME1= 5800.01904 TIME2= 6400.02197 INTTIME= 600.00293 TICASE= 59.2440 TFCASE= 59.7940 TCASE= 59.5190 DELTHT= 0.004888 AVTIME = 6100.020508 XHC= 2.933091 XPANST= 1.00042546 XPANCA= 1.00042701 RWX= 17.930237 RWY= 25.519234 SHP= 43.449471

THIGH= 60.1025 TLOW= 59.7285 Fe= 0.1093196
FeO= 0.1701577 KCl= 0.1651831 FeS2= 0.1297736
MgO= 0.2337647 Li= 0.8781325 Al= 0.2196395
LiF= 0.4034294 LiBr= 0.1439938 LiCl= 0.2862096
HPHC= 0.1334910 AHC= 0.3362171 ECHC= 0.1701063
EUT= 0.2001285 SHC= 0.1764368 XHC= 1.65636
CPINS= 0.2044648 CPHPAP= 0.1400
TSTSTHC= 0.112810 THPHC= 0.369623 TSHC= 0.040585
TECHC= 0.388868 TINSHC= 0.283950 TINSTHC= 0.048023
TAHC= 0.300550 TPAPHC= 0.132348
T1= 332.878479 T2= 333.252502 TEUTFUS= 0.0000000

K= 0.3971423954E-02 TAVSTACK= 59.916 TAVINS= 59.927 TIME1= 6400.02197 TIME2= 6800.00488 INTTIME= 399.98291 TICASE= 59.7940 TFCASE= 60.0850 TCASE= 59.9395 DELTHT= 0.004141 AVTIME = 6600.013672 XHC= 1.656363 XPANST= 1.00043154 XPANCA= 1.00043178 RWX= 17.930389 RWY= 25.519451 SHP= 43.449841

THIGH= 60.9405 TLOW= 60.1025 Fe= 0.1093671
FeO= 0.1702072 KCl= 0.1651918 FeS2= 0.1298636
MgO= 0.2339114 Li= 0.8787099 Al= 0.2197063
LiF= 0.4036954 LiBr= 0.1440149 LiCl= 0.2862584
HPHC= 0.1335358 AHC= 0.3363743 ECHC= 0.1701985
EUT= 0.2001792 SHC= 0.1765553 XHC= 3.71271
CPINS= 0.2045167 CPHPAP= 0.1400
TSTSTHC= 0.252856 THPHC= 0.828400 TSHC= 0.090989
TECHC= 0.871714 TINSHC= 0.636339 TINSTHC= 0.107640
TAHC= 0.673683 TPAPHC= 0.296520
T1= 333.252502 T2= 334.090485 TEUTFUS= 0.0000000

K= 0.2425040584E-03 TAVSTACK= 60.521 TAVINS= 60.454 TIME1= 6800.00488 TIME2= 9409.99609 INTTIME= 2609.99121 TICASE= 60.0850 TFCASE= 60.6880 TCASE= 60.3865 DELTHT= 0.001423 AVTIME = 8105.000488 XHC= 3.712714 XPANST= 1.00043857 XPANCA= 1.00043702 RWX= 17.930580 RWY= 25.519726 SHP= 43.450306 HFUSEC = 17.5326 HFUSA = 7.02 HFUSEUT = 70.2 ECMASS = 6.112 ANODEMASS = 2.390 HPELLETMASS = 7.403 STEELSTACKMASS = 2.759 INSMASS = 7.426 HEAT PAPER MASS = 5.056 SULFUR MASS = 0.615 MASS STEEL IN INS = 2.349

A-4. Graphical Global Thermal Conductivity Values for the LCCM Thermal Insulation Package

The exact effect of the gas composition of operating atmosphere thermal battery gas mixtures on the global thermal conductivity of the thermal insulation package must be known to optimize battery operation in the field. Global thermal conductivity values measured for the LCCM thermal insulation package for gases and gas mixtures are shown in figures A-1 through A-4 using more examples and clearer detail than could be shown in figure 1 of the main report. All of the values shown were calculated as shown in sections A-1 through A-3. For the transient experiments, measured thermal conductivity values from -20 to +40 °C most closely approach the quasi-steady-state thermal conductivity values that will be apply at the insulation temperatures shown.

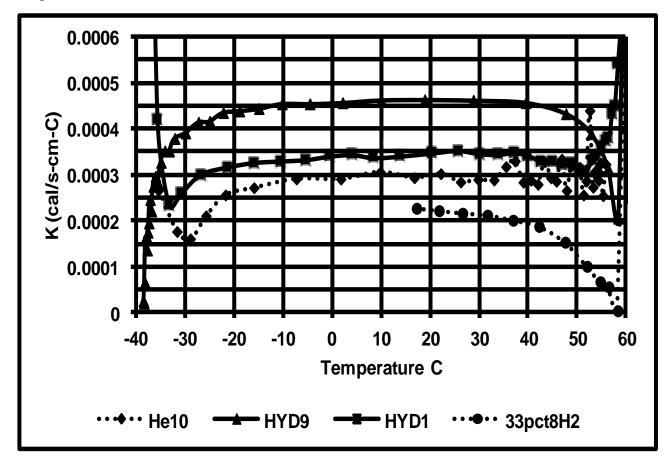


Figure A-1. LCCM global thermal insulation package thermal conductivity values for helium at 10 atmospheres absolute, for hydrogen at 9 atmospheres and at 1 atmosphere absolute, and for a 33/67 volume percent hydrogen/air mixture at 8 atmospheres absolute.

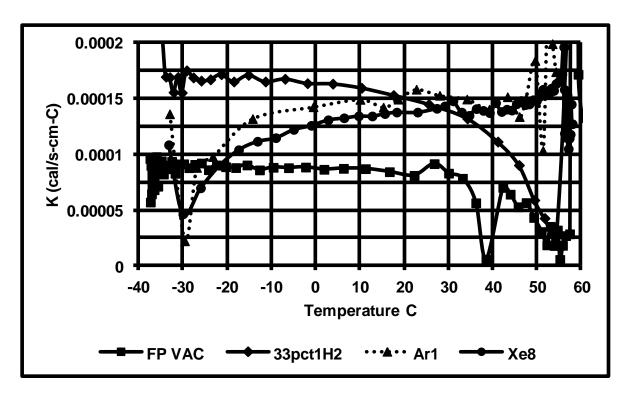


Figure A-2. LCCM global thermal insulation package thermal conductivity values for a fore pump vacuum atmosphere (~6.7 Pa), for a 33/67 volume percent hydrogen/air mixture at 1 atmosphere absolute, for argon at 1 atmosphere absolute, and for xenon at 8 atmospheres absolute.

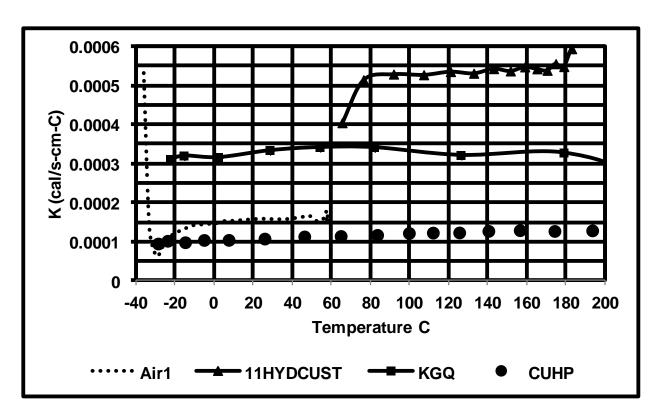


Figure A-3. LCCM global thermal insulation package thermal conductivity values for air at one atmosphere absolute, for pure hydrogen at 11 atmospheres absolute as measured using the copper-heat pellet high temperature transient experiment, for the LCCM thermal battery GPS9Q quasi-steady-state experiment, hermetically sealed containing 1 atmosphere of dry room air and then initiated as the cell stack cooled from nominally 550 °C to –40 °C, and for a the copper-heat pellet stack quasi-steady-state experiment built into an LCCM configuration as the copper disks cooled from nominally 500 °C to –40 °C in a fore pump vacuum.

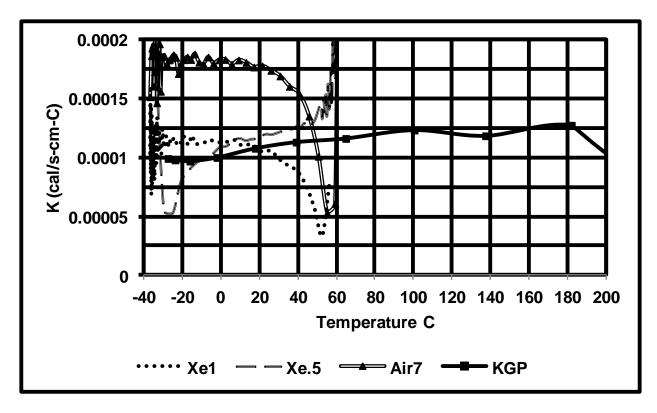


Figure A-4. LCCM global thermal insulation package thermal conductivity values for xenon at 1 atmosphere absolute, for xenon at 0.5 atmosphere absolute, for air at 7 atmospheres absolute, and for the LCCM thermal battery GPS9P quasi-steady-state experiment as the cell stack cooled from nominally 550 °C to -40 °C in a fore pump vacuum as described in reference 1. The Xe.5 heating curve appears to become increasingly contaminated with higher thermal conductivity gases as it approaches 60 °C near the end of the experiment.

A-5. Tabular Global Thermal Conductivity Values for the LCCM Thermal Insulation Package

Tabular values of the output parameter K measurements (in cal/s-cm-°C) at the global LCCM thermal insulation package temperatures TAVINS from the Fortran output file shown in section A-3 were used to make the graphs used in figures A-1 through A-4 and in figures 1 and 2 in the main report. Those tabular values are shown for convenience and precision in tables A-1 and A-2. The tabular values shown below are copies of the Excel spreadsheet data originally used to make those graphs.

Table A-1. Tabular global thermal conductivity values for the LCCM thermal insulation package. Thermal conductivity values are shown in cal/s-cm- $^{\circ}$ C.

TIME C	Uo10	TINIC C	ED VAC	TIME C	HVD0	TIME C	UVD4	TIME C	22not4LI0	TIME C	22no+0LI0	TIME C	A r1
	He10 0.000266		FP VAC 0.000129		HYD9 0.000774		HYD1 0.002797		33pct1H2 0.000952		33pct8H2 1.107087		Ar1 0.000136
	0.000266		0.000129		0.000774	-36.239	0.002797	57.981			0.001164	-32.967	2.24E-05
	0.000177		0.000172		0.000206		0.000423	54.521			4.34E-06		8.81E-05
	0.000211		2.87E-05	56.328			0.000236	51.765			5.65E-05	-23.245	9.78E-05
	0.000256	56.525		52.828	0.00039		0.000262	49.438	5.9E-05		6.74E-05		0.000132
-15.947			1.83E-05	47.695			0.000302	45.963			0.000101	-0.547	0.000142
-7.285	0.000291	55.197	5.71E-06	39.5	0.000457	-21.431	0.000319	41.163	0.000111	47.555	0.000154	10.056	0.000149
1.775	0.000291	54.654	3.21E-05	28.804	0.000462	-15.878	0.000328	34.285	0.000132	42.225	0.000188	15.294	0.000142
9.809	0.000306	53.901	1.82E-05	18.896	0.000464	-10.52	0.000332	25.573	0.000145	36.918	0.000201	18.637	
16.764	0.000294	53.034	3.53E-05		0.000463	-5.415	0.000335	17.596	0.000153	31.686	0.000212	22.755	0.000158
	0.000303		1.87E-05		0.000457		0.000342		0.000159		0.000217		0.000153
	0.000285	51.009	3.07E-05	-4.539			0.000345		0.000163		0.000222	34.178	
29.795	0.00029	49.302	4.33E-05		0.000455		0.000339		0.000164	17.242	0.000227	39.223	0.00014
	0.000289	47.587	5.66E-05		0.000444		0.000342		0.000167			43.349	
35.463		45.781			0.000439		0.000349		0.000165			46.04	
37.317	0.00033	43.99	6.42E-05	-22.21			0.000354		0.000171			47.515	0.00015
	0.000284		7.02E-05		0.000417		0.000348		0.000165				0.000184
40.535	0.000288	38.511		-27.265	0.000415		0.000346		0.000172				0.000103
41.974 43.354	0.00028	36.206	5.65E-05 7.84E-05	-29.905	0.000391	36.956 39.865	0.00035 0.000344		0.000167 0.000166			52.373	0.000229
43.354		30.061	8.3E-05		0.000379		0.000344		0.000166				0.000199
	0.000294		9.15E-05		0.000352	44.751	0.000331		0.000169			J+.ZU0	0.000174
	0.000230	22.281	8.1E-05		0.000332		0.00033		0.000175				
	0.000266		8.43E-05		0.000282		0.000326		0.000169				
48.739	0.00032	11.273	8.7E-05	-36.009		50.258	0.00031		0.000156				
49.637		6.3		-36.465			0.000309		0.000169				
	0.000316		8.65E-05		0.000222		0.000333		0.000169				
51.267		-2.262	8.84E-05		0.000247	53.932	0.00034		0.000202				
51.864	0.000287	-6.108	8.79E-05	-37.365	0.000196	54.847	0.000364						
52.545	0.00044	-9.576	8.82E-05	-37.565	0.000175	55.653	0.000376						
53.221	0.000273	-12.666	8.59E-05	-37.71	0.000137	56.352	0.000382						
53.831	0.00031	-15.489	9.03E-05	-37.844	0.000165	56.96	0.000435						
54.344		-18.054	8.8E-05	-37.987	0.000164		0.000451						
54.799			8.87E-05	-38.194			0.000542						
	0.000255	-22.389		-38.378	2.09E-05		0.000661						
55.818	0.000323		8.61E-05	-38.474	2.56E-05		0.000924						
		-25.794					0.003971						
			9.09E-05			60.454	0.000243						
		-28.637 -29.796											
			9.14E-05 9.13E-05										
		-31.751											
		-32.508											
		-33.238											
			8.69E-05										
			8.22E-05										
			9.39E-05										
		-35.298	9.12E-05										
			7.13E-05										
			9.78E-05										
			8.53E-05										
			6.81E-05										
			9.73E-05										
			8.82E-05										
			6.44E-05										
			8.99E-05										
			5.71E-05										
		-37.425	9.61E-05										

Table A-2. Tabular global thermal conductivity values for the LCCM thermal insulation package. Thermal conductivity values are shown in cal/s-cm- $^{\circ}$ C.

TINS C	Xe8	TINS C	Xe1	TINS C	Xe.5	TINS C	Air7	TINS C	Air1	TINS C	11H2CUST	TINS	KGQ	TINS	CUHP	TAVINS	KGP	
	0.000108		7.57E-05		0.000461		0.000474						5.89E-05					
	4.65E-05		3.34E-05		0.000234		6.1E-05						0.000254				9.88E-05	
	6.98E-05		5.49E-05		5.56E-05	55.082			6.35E-05				0.000327					
	9.01E-05		7.28E-05		5.28E-05		0.000101	-24.969	9.85E-05	107.2706	0.000528	126.5705	0.000321	193.5389	0.000129	137,4444	0.000118	
	0.000104		8.54E-05		7.96E-05		0.000135		0.000121				0.000341				0.000123	
	0.000112	37.366	9.14E-05		8.95E-05		0.000154						0.000341			64.77788	0.000116	
-9.005	0.000115	33.547	9.45E-05	-12.602	9.61E-05	35.491	0.00016	-11.569	0.000141	143.0447	0.000543	28.65363	0.000333	140.3994	0.000128	39.00938	0.000113	
-4.968	0.000122	29.861	9.92E-05	-8.493	9.95E-05	30.611	0.000169	-7.251	0.000144	151.6556	0.000538	2.34725	0.000315	125.473	0.000124	17.80475	0.000108	
-0.997	0.000126	26.215	0.000106	-4.577	0.000103	25.879	0.000174	-3.086	0.000146	159.0104	0.000548	-15.1804	0.000319	111.9859	0.000123	-2.1095	0.0001	
2.826	0.000131	22.681	0.000104	-0.809	0.000109	21.331	0.000178	0.874	0.000147	165.2863	0.000543	-22.3175	0.00031	99.72743	0.000122	-16.1713	9.69E-05	
6.415	0.000133	19.325	0.000107	2.877	0.00011	17.007	0.000177	4.69	0.000153	170.4624	0.000539			83.46788	0.000117	-23.9161	9.79E-05	
9.718	0.000134	16.003	0.000111	6.394	0.000115	12.925	0.000181	8.358	0.000154	174.8339	0.000556			64.81094	0.000115	-27.5455	9.92E-05	
12.775	0.000134	12.832	0.00011		0.000117		0.000183		0.000154					46.18181	0.000113			
15.629	0.000136	9.839	0.000111	12.848	0.000115	5.457	0.000179	15.087	0.000156	183.0118	0.000594			25.83125	0.000108			
18.311	0.000138	6.899	0.000115	15.826	0.000116	2.071	0.000183	18.179	0.000157	186.2141	0.000628			7.45512	0.000105			
	0.000138		0.000114		0.000116		0.000183		0.000158						0.000104			
	0.000141		0.000112		0.000119		0.00018	23.829		191.4355					9.86E-05			
	0.000143		0.000113		0.00012		0.000185		0.000159						0.000102			
	0.000148		0.000113	26.384			0.000179		0.000158	196.4514	0.001036			-28.6856	9.52E-05			
	0.000138		0.000115		0.000123		0.000181		0.000164									
	0.000135		0.000113		0.000124		0.000188		0.000167									
	0.000141		0.000112		0.000126		0.000183		0.000165									
	0.000139		0.000111		0.000127		0.000185		0.000166									
	0.000137		0.000111		0.000125		0.000183		0.000165									
	0.000146 0.000138		0.000119						0.000152									
	0.000136		0.000111		0.000129		0.000171 0.000185		0.000166									
	0.00014		0.000114		0.000127		0.000187		0.000177 0.000153									
	0.000133		0.000110		0.000132		0.000184		0.000159									
	0.000148		0.000113		0.000140		0.000183		0.000133									
	0.000114		0.000112		0.000151		0.000178		0.000113									
	0.000145		0.000117		0.000138		0.000178	00.001	0.000.00									
	0.000149		0.000114		0.000154		0.000186											
	0.000148		0.000111		0.000135		0.000186											
50.65	0.000152		0.000115		0.000162		0.000186											
51.371	0.000158	-27.493	0.000108	56.05	0.000156	-31.457	0.000156											
52.058	0.000157	-28.248	0.000118	56.47	0.000141	-32	0.000196											
52.681	0.000154	-28.955	0.000108	56.86	0.000168	-32.54	0.00018											
53.261	0.000159	-29.567	0.000111	57.271	0.000174	-33.028	0.000189											
53.804	0.000157	-30.197	0.000124	57.613	0.000143	-33.438	0.000146											
54.312	0.000163	-30.771	0.000103	57.938	0.000199	-33.529	0.00027											
	0.000165		0.000109		0.000172		0.000245											
	0.000167		0.000121		0.000172		0.000173											
	0.000171		0.000103		0.000212		0.000161											
	0.000196	-32.594			0.000237		0.000187											
	0.000158		0.000134		0.000168		0.000195											
	0.000119		9.54E-05		0.000237		0.000186											
	0.000115		9.99E-05		0.000218		0.000193											
	0.000153 0.000105		0.000127 8 13E-05		0.000334		0.000186 0.000152											
	0.000105		8.13E-05			-30.004	0.000102											
	0.000114		0.000126															
	0.000116		8.34E-05															
	0.000143		0.000114															
30.012	5.550 IE7		0.000114															
			7.63E-05															
			0.000135															
			9.38E-05															
			6.8E-05															
			0.000144															
			8.6E-05															
			0.000161															
			9.93E-05															

Appendix B. Hydrogen Oxidation by Barium Chromate

This appendix shows examples of Excel sheet analyses that were used to evaluate the effectiveness of BaCrO₄ as an oxidizer of hydrogen gas. Some gas volume calculations were repeated using alternate methods to check for internal consistency. Hydrogen gas evolution from the LCCM flight test heat paper by itself (section B-1, figures B-1 and B-2) is compared with that of the heat paper initiated when in physical contact with BaCrO₄ (section B-2, figures B-3 through B-5).

B-1. Gas Evolution of LCCM Flight Test Heat Paper

8.65928 Vapor pressure of water at 21 °C torr	18.65928	1												
9.83688 Vapor pressure of water at 22 °C torr	19.83688	3												
9.60136 Vapor pressure of water at experimental tem	perature of 21.8 °C to	rr												
0.23885 Maximum volume of water vapor present at 2	1.8 C in sample bottle	es std atm cc												
.533645 Maximum volume of water vapor present at 2	1.8 C in gas handling	system and I	Min-K Cal std	atm cc										
2.412 Mass of Flight Test Heat Paper used was 2.4	412 g - GPS97-8&9 LI	LS p. 1295												
.562976 Mass of BaCrO4 in Flight Test Heat Paper us	sed a - GPS97-8&9 L	LS p. 1295												
0.607824 Mass of Zr in Flight Test Heat Paper used g	- GPS97-8&9 LLS p.	1295												
0.2412 Mass of Glass Fiber in Flight Test Heat Paper			5											
J	,													
2.412 Check of Flight Test Heat Paper Mass q														т
j i i i i i i i i i i i i i i i i i i i														т
4.5 Density of BaCrO4 is 4.50 g/cc														т
0.347328 Volume of BaCrO4 cc														т
6.52 Density of Zr is 6.52 g/cc														
0.093225 Volume of Zr cc														
2.196 Density of glass (silicon dioxide (vitreous)) g/	cc													
0.109836 Volume of glass fiber in heat paper cc	00													
1.061 Steel burner pad preheated to 700 °C g - GP	207 080 II C n 400E													
0.395 Steel foil 0.003 inch thick preheated to 700 °C g - GP														Н
	cy-Gros/-869 LL	J p. 1290												\vdash
7.87 Density of iron g/cc 0.185006 Total volume of steel cc														\vdash
0.185006 Total volume of Steel CC														-
														-
0.735395 Estimated total solid volume of all componen	its inside Min-K calori	imeter cc												_
There is little evidence from the recorded pret (See report text and figures - see also 21SEf Calculate the total amount of gas formed whe When the first sample bottle was closed the	PTestCurveGroupInstr	rinc (Autosave	d).xls Excel \	Workbook) ed, just before	the desiccate	or was opened,	and at th	e end of th			gures			
(See report text and figures - see also 21SEF Calculate the total amount of gas formed who When the first sample bottle was closed the This experiment was initiated with sample bo	PTestCurveGroupInstr	rinc (Autosave d sample bott Min-K cal was I closed - GPS	d).xls Excel \ les were clos not known be	Workbook) ed, just before cause of the re	the desiccate	or was opened, ates caused by	and at th	e end of the	see report		gures			
(See report text and figures - see also 21SEF Calculate the total amount of gas formed whe When the first sample bottle was closed the This experiment was initiated with sample bo Sample bottle A20SEP2011 was opened and	PTestCurveGroupInstrenthe first and secongas pressure in the Mottle SB A20SEP2011	rinc (Autosave	d).xls Excel \ les were clos not known be 597-8&9 LLS 3.397 second	Workbook) ed, just before cause of the re pp. 1299-1300 Is with a final p	the desiccate	or was opened, ates caused by 12.9716 torr - G	and at the mete	e end of the ring valve -	see report	text and fig				
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(See report text and figures - see also 21SEF Calculate the total amount of gas formed whe When the first sample bottle was closed the This experiment was initiated with sample be Sample bottle A20SEP2011 was opened and (See 21SEPTestCurveGroupInstrinc (Autosav 7.60467 Transducer voltage at one atmosphere - Aver 1.13041 Transducer voltage when SB A20SEP2011 w 16 Time elapsed from start of program to initiatic 93.397 Time elapsed from start of program to closing 273.15 Temperature at 0 °C in Kelvin 760 Gas pressure at one atmosphere torr 112.9716 Digitally recorded gas pressure inside the sa 10 Physical volume of sample bottle SB A20SE 21.8 Dry room air temperature when sample bottle 3.76602 Volume of gas in closed sample bottle SB A 20.039 Physical volume of Min-K calorimeter (38.94' 74.9449 Physical volume of gas handling system plus 2380.42 Physical volume of desiccator and butyl tube 3.143024 Maximum transducer voltage recorded electre	PTestCurveGroupInstrem the first and secongas pressure in the first and secongas press	rinc (Autosave d sample bott din-K cal was closed - GPS liy 89.997 to 9 ook in Docum VBGET LLS p ded data V - S s EP2011 when as closed °C 7 s from start of and Min-K calorime gas sample vo ' minutes and	Ides were closen not known be sort-aken lust a lust some	Workbook) ed, just before cause of the re pp. 1299-1300 Is with a final pt. 12011GasEvol 197-889 LLS p. 197-889 LLS p. 197-889 LLS p. 197-889 LLS p. 1475.797) secon	the desiccate deduced flow in the desiccate of 11 unionTEST for 1,1300 and of program an program - S & p. 1265 and 265	or was opened, ates caused by ates caused by 12.9716 torr - G idder on LS1329	and at the the meter the meter state of the meter s	e end of the hirring valve - 9 LLS p. 1: 9 LLS p. 1: 151.087 112.9716 151.087 112.9716 175.797	iono increasing a corri) Pressure (314.1094	egain at 93. Press Voll 1.511798 1.13041 torr)	397 second	age	1 2)	
Calculate the total amount of gas formed whe When the first sample bottle was closed the This experiment was initiated with sample bottle was opened and (See 21SEPTestCuneGroupInstrinc (Autosan 7.60467 Transducer voltage at one atmosphere - Aver 1.13041 Transducer voltage when SB A20SEP2011 was 16 Time elapsed from start of program to closing 273.15 Temperature at 0 °C in Kelvin 760 Gas pressure at one atmosphere torr 12.9716 Digitally recorded gas pressure inside the sa 10 Physical volume of sample bottle SB A20SE 21.8 Dry room air temperature when sample bottle SB A20SE 3.8 41 Physical volume of gas in closed sample bottle SB A20SE 3.8 41 Physical volume of gas handling system exc 38.941 Physical volume of gas handling system plus 2380.42 Physical volume of desiccator and butyl tube	PTestCurveGroupInstrement the first and secongas pressure in the first and secongas pr	rinc (Autosave d sample bott lin-K cal was l closed - GPS lly 89.997 to 9 ook in Docum VBGETLLS p ded data V - S s EP2011 when as closed °C 7 s from start of 3 s p. 1265 lin-K calorimgas sample vc minutes and 14	d).xls Excel \(\text{les were clos} \) not known be \(\text{S97-8&9 LLS} \) 3.397 seconce \(\text{entiles} \) 3.397 seconce \(\text{entiles} \) 5.6) See Also GPS of program storimeter cc G of program storimeter cc G eter cc GPS9 plume cc GPS 56 seconds (614 seconds (614	Workbook) ed, just before cause of the re pp. 1299-1300 swith a final pp. 120011GasEvol 197-8&9 LLS p. 1397-8&9 LLS p. 1475.797) seconds seconds) after the seconds of the property of the	the desiccate deduced flow in program of pro	or was opened, ates caused by ates caused by 12.9716 torr - Gilder on LS1329	and at the meter the meter state of the meter state	e end of thiring valve - SLLS p. 1: 1 SLLS p. 1 SLLS p. 1: 1 SLLS p. 1 SLLS p. 1: 1 SLLS p. 1 SLLS p. 1: 1 SLLS p. 1 SLLS p. 1: 1 SLLS p. 1: 1 SLLS p. 1: 1 SLLS p. 1 SLLS	iono increasing a corri) Pressure (314.1094	egain at 93. Press Voll 1.511798 1.13041 torr)	397 second	age	2)	
(See report text and figures - see also 21SEf Calculate the total amount of gas formed whe When the first sample bottle was closed the This experiment was initiated with sample bot Sample bottle A20SEP2011 was opened and (See 21SEPTestCurveGroupinstrinc (Autosa) 7.60467 Transducer voltage at one atmosphere - Aver 1.13041 Transducer voltage when SB A20SEP2011 w 16 Time elapsed from start of program to ribitatic 93.397 Time elapsed from start of program to closing 273.15 Temperature at 0 °C in Kelvin 760 Gas pressure at one atmosphere tor 112.9716 Digitally recorded gas pressure inside the sa 10 Physical volume of sample bottle SB A20SE 21.8 Dy room air temperature when sample bottle 3.76602 Volume of gas in closed sample bottle SB A26.0039 Physical volume of gas handling system exc 88.941 Physical volume of gas handling system plus 2380.42 Physical volume of gas handling system plus 2380.42 Physical volume of gas recorded electra 3.142 Maximum transducer voltage recorded electra 3.15 Maximum transducer voltage recorded manual	PTestCurveGroupInstrement the first and secongas pressure in the first and secondary and seco	rinc (Autosave d sample bott //in-K cal was closed - GPS ly 89.997 to 9 ook in Docum VBGET LLS p ded data V - S s EP2011 when as closed °C 7 s from start t and Min-K calc S.p. 1265 wijn-K calor invites and inutes and 14 siccator valve la	Iles were clos not known be S97-8&9 LLS 33.397-8econe ents/26Augus b. 6) see Also GPS of program strorimeter cc G ster cc GPS9 slume cc GPS	Workbook) ed, just before cause of the re pp. 1299-1300 s with a final pt. 12011GasEvol 197-8&9 LLS p. 1987-8&9 LLS p. 19897-8&9 LLS p. 1987-8&9 LS p	the desiccate deduced flow in pressure of 11 utionTEST for 1300 art of program - S 6 p. 1265 2265 1269 and after the program conds after the program c	or was opened, ates caused by ates caused by 12.9716 torr - Gldder on LS1329 Till torr ee also GPS97 program was started to the program was started to the program was	and at the meter the meter state of the meter state	e end of thiring valve - SLLS p. 1: 1 SLLS p. 1 SLLS p. 1: 1 SLLS p. 1 SLLS p. 1: 1 SLLS p. 1 SLLS p. 1: 1 SLLS p. 1 SLLS p. 1: 1 SLLS p. 1: 1 SLLS p. 1: 1 SLLS p. 1 SLLS	iono increasing a corri) Pressure (314.1094	egain at 93. Press Voll 1.511798 1.13041 torr)	397 second	age	2)	
Calculate the total amount of gas formed whe When the first sample bottle was closed the This experiment was initiated with sample bottle bott	PTestCurveGroupInstrem the first and secongas pressure in the first and secongas press	rinc (Autosave Id sample bott In-K cal was Iclosed - GPS Illy 89.997 to 9 ook in Docum VBGET LLS p ded data V - S s EP2011 when as closed °C 7 s from start t and Min-K calt S. p. 1265 Win-K calorime gas sample vo minutes and intest and i	Ids were clos not known be S97-8&9 LLS 33.397 second ents/26Augus 6.6) See Also GPS of program stonometer cc G seconds (61/26Seconds) 56 seconds (61/26Seconds) 57 seconds (61/26Seconds) 58 seconds (61/26Seconds) 58 reacco	Workbook) ed, just before cause of the re pp. 1299-1300 pp. 1299-1300 swith a final pt. 12011GasEvol 997-889 LLS p. 197-889 LLS p. 1987-889	the desiccate deduced flow in the desiccate deduced flow in the desiccate deduced flow in the desiccate de	or was opened, ates caused by ates caused by 22.9716 torr - Gidder on LS1329 Ti a torr ee also GPS97 program was st was started to the program was st arm was started at the strength of the program was started at the strength of the strengt	and at the meter	e end of the firing valve - 9 LLS p. 1: 9 LLS p. 1: 151.0877 112.9716 475.797 withy after r. 7888 LLS	Pressure (314,1094	egain at 93. Press Voll 1.511798 1.13041 torr)	397 second	age	2)	

Figure B-1. Gas evolution of LCCM flight test heat paper.

	1						-			Ī									
	MV2 was c	ompletely	opened by	8 minutes	and 23 s (50	03 seconds)	after the	start of the	program t	o allow the	gas pressur	e to equilibr	ate betwee	en GHS and	Min-K Cal	- GPS97-88	9 LLS pl 1	300	
;	Sample bot	ttle A20SE	P2011 was	closed 1	minute and 3	33 seconds	(93.397 s	econds) af	er the star	t of the expe	eriment with	the electron	nic transdu	cer voltage	at 1.13041	olt - GPS97	7-8&9 LLS	p. 1300	
;	Sample bot	ttle B20SE	P2011 was	closed 12	minutes an	d 16 second	ls (736 s	econds) aft	er the start	of the expe	riment with	the manuall	ly read trar	nsducer volta	age at 2.68	7 volt - GPS	97-8&9 LL	S p. 1300	
2.687 I	Manual tran	nsducer vo	tage readin	ig when sa	mple bottle	B20SEP201	1 was cl	osed at 12	minutes ar	nd 16 s (736	seconds) fr	om start of	program V	- GPS97-88	%9 LLS p.1	300			
3.535 I	Manual tran	nsducer ga	s pressure	of SB B20	SEP2011 cl	osed at 736	seconds	from start	of program	torr - GPS9	97-8&9 LLS	p.1300				Trans Volt	Time	Pressure (to	orr)
					320SEP2011					U			CurveGroup	Instrinc.xls		2.687227	736.097	268.5576	
					SEP2011 at														
														Cal - GPS97	-8&9 LLS p	.1300			
6615	Total volum	e of gas e	olved meas	sured at 73	6.097 secor	nds (includin	ig the gas	s in SB A20	SEP2011)	std atm cc	- GPS97-88	39 LLS p.13	300						
																Trans Volt		Pressure (to	orr)
				d time and	pressure da									ls		2.708747	838.197	270.7083	
	Time (s)					m GPS97-88						(Autosave	d).xls						
_					on is 16 sec		s recorde	ed manually	- GPS97-	8&9 LLS p.	1300								
_					corded pres														
					A20SEP201			1	1										
					A20SEP201				_		9								
					e A20SEP2								laaaa						
					e A20SEP2					r2011 - No	e pressure	arop on repl	iacement						
					ng MV2 basi			sure measi	rements										
					ure of entire			0000011											
					before open														
					er opening s				anura tima	trans Con	alaa CDC0	7 00 0 1 1 0 1	n 1200						
					sing sample								p. 1300						
					sing MV2 - efore (~.1 s					bullon when	D7 Was upe	eneu							
					pening valve			aive to desi	Juanui										
					pening valve			t hefore ren	nening M\/	2									
					ure measure					2									
				• .	red with des					onen									
					red with des														
					red with des														
					pressure m						wide onen								
	1002.201	0.000420	Last data	John Gas	picoouic ii	Casarca wit	II desiece	ator varve b	7 Opcii ivi	VZ IGIIIQIIIS	wide open								
18069	Total measi	ured nas n	resent in G	HSYS and	Min-K Cal	at 838 197 s	econds f	rom start o	nrogram s	td atm cc -	GPS97-880	11 S n 130	0						
														atm cc - Alte	emate calc	ulation meth	od		
					measured at				•										
	Jan Jan U						. ". ".			, , , , , , , , , , , , , , , , , , , ,		. 35	, 50	1					
08425	Pressure in	n system a	t 1682.297	seconds a	t the very er	nd of the exp	eriment t	torr											
					+ Desiccato				CC										
					in system a					moved in sa	ample bottle	s std atm c	С						
														slightly with	the ash in	this 21 Sep	2011 test		
					Total gas e	evolved sumr	mary												
		25.95307	Maximum	total gas e	volution am	ount - measi	ured at 4	75.797 sec	onds after t	the program	was started	d std atm co	3	25.95307					
		25.6615	Total volun	ne of gas e	volved meas	sured at 736	.097 sec	onds std at	m cc					25.6615					
		25.82977	Total gas	evolved me	asured at 83	38.197 seco	nds just l	before open	ing desicca	ator std atm	CC			25.82977					
		25.22841	Total evolv	ed gas me	asured at 16	82.297 sec	onds afte	r opening d	esiccator i	ncluding sar	mple bottles	std atm cc		25.22841					
		10.70886	Total gas	evolved me	asured at 83	38.197 seco	nds just b	before open	ing desicca	ator per grar	n of heat pa	per std atm	cc/g	10.70886					
		10 45054	Lact data	noint Con	nraccura m	accured wit	h desires	ator valva R	7 onen - M	V2 remains	wide open			10.45954					

Figure B-2. Gas evolution from LCCM flight test heat paper.

B-2. Gas Evolution of LCCM Flight Test Heat Paper in Contact with BaCrO₄

Times noted on this spreadshee	ara rafarrad to tima	70rn /12 306	cannot after the date	a annuicition nronra	m ctart) unla	acc athonuica natad											
14.69594 One Atmosphere psi	ale lelelled to tillle	2610 (12.330	Seconds after the date	a acquisition progra	II Start) urin	555 ULICIWISE HULEU											
101325 One Atmosphere Pa																	-
B.314472 Molar Gas Constant J/mol-K (or	Do ==3/===1 I/\	404 2054	ioulan liter atm	404.0	nne	404 2074											
		101.3231	joules/liter-atm	101.3	(90	101.3271											-
0.082057 Molar Gas Constant liter-atm/mo																	-
22.41398 Liters in one mole of an ideal ga	at SIP - V=NRI/P																-
18.015 Molecular weight of water g																	
Some data is reported to more s	ignificant figures thar	n justified for	convenience when wo	rking with Excel and	to simplify	mathematical debu	gging analyses	i									
18.6593 Vapor pressure of water at 21 °C	torr		18.65928														
19.8369 Vapor pressure of water at 22 °C	torr		19.83688														
19.8369 Vapor pressure of water at expe	imental temperature	of 22.0 °C to	rr														
.241556 Maximum volume of water vapor	present in one samp	le bottle std	atm cc														
.000194 Maximum weight of water vapor	oresent in sample bo	ttles g															
18.015 Molecular weight of water g - ch	eck																
.545071 Maximum possible volume of wa	ter vapor at 22.0 C in	gas handlin	system and Min-K C	Cal containing heat p	aper ash ar	nd steel solids std a	tm cc - Does n	ot include s	ample bottle								
.028184 Maximum possible volume of wa	ter vapor in both sam	ple bottles a	nd gas handling syste	em at 22.0 C std atn	1 00												
2.4224 Mass of Flight Test Heat Paper	used was 2.4224 g -	GPS97-8&9	LLS pp. 1336, 1340														
1.095 Mass of BaCrO4 powder used w	as 1.0950 g - GPS97	7-8&9 LLS pp	. 1336, 1340														
0 Mass of NBS H-350-39 350 cal/				er) used g - GPS97-I	8&9 LLS pp.	1336, 1340											
.569715 Mass of BaCrO4 powder in heat				1													
0 Mass of BaCrO4 powder in heat																	
.664715 Total Mass of BaCrO4 q		2 7. 10															
4.5 Density of BaCrO4 is 4.50 g/cc																	
.592159 Total volume of BaCrO4 cc																	
.610445 Mass of Zr powder in heat paper	n - GPS07-880 S	nn 1336 13	40														
Mass of Zr powder in heat powd	•																-
.610445 Total Mass of Zr present g	a y - O1 031-043 LL	о рр. 1000, 1	040														-
																	-
6.52 Density of Zr is 6.52 g/cc																	-
.093627 Total volume of Zr cc																	-
0.24224 Mass of glass fiber in heat pape	•																-
2.196 Density of glass (silicon dioxide																	_
0.11031 Total volume of glass fiber in hea	t paper cc																-
2.4224 Check of heat paper mass g																	-
O Check of heat powder mass g																	\vdash
O Check of fleat powder fliass g																	-
1.0725 Steel burner pad ~1.125 inch dia	material 0.440 incl	h shialr araba	atad to 700 00 a OD	007 000 110 - 40	ne .												-
					50												-
0.3887 Steel foil ~1.125 inch diameter	y u.uu3 inch thick p	reneated to /	w ~c g - GPS9/-8&9	LLS p. 1336													-
7.87 Density of iron g/cc																	-
.185667 Total volume of steel cc													-				-
																	-
201700 5 11 11 11 11 11 11 11		NE IZ		11. 21													-
.981762 Estimated total solid volume of a	II components inside	Min-K calor	meter before (and afte	er) ignition cc													-
The first sample bottle was label	ad 07102012∆ _ CEDG	07.880110	n 1340														
The second sample bottle was label																	
Time zero used for the pressure				rico (12 206 aacaa	do after the	nrogram otast). Car	PLEASE PROPERTY	HOCETAGE	rooh vlo i-	tha Danie	onte/TD4 f	ldor of LO	12204				
						,	: D 1 TC 42 OJULY 2	IZUE IEST	napii.XIS IN	IIIE DOCUM	3115/1K4 IC	inei (il F2)	13234				-
Times for closing the sample bo							una alcoration	07.0 a) :	hafar th	laning et e		(44.40.0	\ and -t t	and of the		(0445.0 -)	-
Calculate the total amount of ga				, ,			,				_		"	ena of the	experiment	(2445.3 S)	-
When the first sample bottle was									metering va	ive - see re	роп text a	na tigures					-
There is evidence from the recor																	
There is evidence from the recor								ithout prod	ucing additio	nal gas							
There is evidence from the recor																	
The recorded pressure-time curv	e Data INSTR 97_26	_2012 14_26	i_06 is also shown in t	the Documents/PS0	2012LS132	94EEEEF folder on	LS13294 - Se	e GPS97-8	&9 LLS p. 1	341							
(See report text and figures note	d above - see also b	TR426JULY2	012GETestGraph.xls E	Excel Workbook in	Documents/	TR4 folder on LS13	294)										
			ot produced by the rea														

Figure B-3. Gas evolution from LCCM flight test heat paper in physical contact with BaCrO₄.

The data suggests that significant amounts of hydrogen gas are not produced by the reaction of water (vapor or liq	wid with the ech but further	ovnorimental	confirmation of this	ic nooded				
	quid) with the ash but lutther	experimental	coniirmation of this	is needed				
This experiment was initiated with sample bottle SB 07192012A open - GPS97-8&9 LLS pp. 1338-1340								
Sample bottle SB07192012A was closed ~99.6 seconds after heat paper ignition with the manually read transduce	er gas pressure at 0.253 volt	- GPS97-8&9	LLS p. 1340 and r	ecorded press	ure-time curve			
.51935 Measured Agilent voltage at room pressure on 25 July 2012 1658 HRS - GPS97-8&9 LLS p. 1337								
7.6 Transducer reading at 760 torr is 7.60 V (MKS calibration)								
0.253 Manually read transducer voltage when sample bottle 07192012A was closed ~99.6 seconds after heat paper ignit 15 Manually recorded time elapsed from start of program to initiation of pyrotechnic s - GPS97-889 LLS p. 1340	tion V - GPS97-8&9 LLS p.1	340						
112 Manually recorded time elapsed from start of program to closing of sample bottle 07192012A s - GPS97-8&9 LLS	p. 1340							
273.15 Temperature at 0 °C in Kelvin								
760 Gas pressure at one atmosphere torr								
5.53642 Digitally recorded gas pressure of gas inside the sample bottle 07192012A when closed at ~99.6 s after heat pape	er ignition torr							
25.3 Gas pressure inside the sample bottle 07192012A from manual reading of transducer when closed ~99.6 s after he	eat paper ignition torr - GPS	97-8&9 LLS p	1340					
10 Internal physical volume of sample bottle 07192012A cc		64.9449						
22 Dry room air temperature when sample bottle 07192012A was closed °C - GPS97-8&9 LLS p. 1340								
0.31096 Volume of gas in closed sample bottle 07192012A at ~99.6 s after heat paper ignition std atm cc - GPS97-8&9 LL	LS p.1340							
26.0039 Internal physical volume of gas handling system excluding sample bottle and Min-K calorimeter cc GPS97-8&9 LL	LS p. 1258, p. 1265							
38.941 Internal physical volume of Min-K calorimeter is 38.9410 cc GPS97-8&9 LLS p. 1265								
3.96314 Internal physical volume of gas handling system plus one sample bottle plus Min-K calorimeter minus solid ash co	c GPS97-8&9 LLS p. 1265							
3.96314 Internal physical volume of gas handling system plus two sample bottles plus Min-K calorimeter minus solid ash c	cc GPS97-8&9 LLS p. 1265							
2380.42 Internal physical volume of desiccator and butyl tube used to expand the gas sample volume cc GPS97-8&9 LLS	p. 1269							
0.24389 Gas pressure measured electronically at 517.3 seconds from time zero (shortly before opening MV2 for sample bo	ottle 07192012B collection)							
0.422 Maximum transducer voltage measured manually 9 minutes and 13 seconds (553 seconds) after the program was		p. 1340						
42.2 Maximum gas pressure recorded manually - measured manually 9 minutes and 13 seconds (553 seconds) after the								
286904 Gas present in GHS and Min-K Cal at 9 minutes and 13 seconds after the program was started (time and voltage			es not include the	gas in closed	sample bottle	SB07192012A		
134545 Electronically measured gas present in GHS and Min-K Cal at 517.3 seconds from time zero std atm cc - Does no				J	,			
.445505 Electronically measured total gas evolution amount at 517.3 seconds from time zero including gas in sample bottle	•							
Metering valve MV2 was opened shortly after ~517.3 seconds from time zero to allow the gas pressure to equilibra		lin-K Cal (see	electronic pressur	e-time curve)				
2.56114 When MV2 was opened shortly after 517.3 seconds the pressure increased to 42.56114 forr by 524.9 seconds - S								
3.315033 Electronically measured gas present in GHS and Min-K Cal at 524.9 seconds from time zero std atm cc - Does no								
6.625993 Electronically measured gas present at 524.9 seconds from time zero including the gas in sample bottle 07192012								
19.86007 The gas pressure then gradually reduced until 667.001 seconds, shortly before the sudden pressure reduction from	n opening sample bottle 071	92012B was r	ecorded (torr at 66)	7.001 s)				
3.10465 Electronically measured gas present in GHS and Min-K Cal at 667.001seconds from time zero std atm cc - Does	not include the gas in close	d sample bott	e 07192012A std a	tm cc				
3.41561 Electronically measured gas present at 667.001 seconds from time zero including the gas in sample bottle 071920	012A shortly before opening	sample bottle	07192012B std atr	m cc				
	, , , , , , , , , ,							
By manual records samole bottle 07192012B was closed 13 minutes and 40 seconds from the program start or 13	3x60+40-12.396=807.6 seco	nds after time	zero					
By manual records sample bottle 07192012B was closed 13 minutes and 40 seconds from the program start or 13 3 25836 The electronically recorded cas pressure at 807.6 seconds was 33 25836 for	3x60+40-12.396=807.6 seco	nds after time	zero					
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3.25836 The electronically recorded gas pressure at 807.6 seconds was 33.25836 torr .590451 Electronically measured gas present in GHS and Min-K Cal at 807.6 seconds from time zero std atm cc - Does no								
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Figure B-4. Gas evolution from LCCM flight test heat paper in physical contact with $BaCrO_4$.

16403 Total volur	ima of age a			zoro (Includor	GHS Min.K	Cal and hot	h aamala bi	attlac) etd att	m cc - GP90	17 00 0 1 1 0 5 40	10							
		olved measured at 8																
6403 Total volur	ıme of gas e	olved measured at 8	17.6 s after time	zero (Includes	GHS, Min-K	Cal, and bot	h sample b	ottles) std atr	m cc - Alterna	ate method - GF	'S97-8&9 LLS	p.1340						
		lly recorded time and							GETestGraph	n.xls in Documer	its/TR4 folder	on LS13294						
		12.396 seconds afte																
Ignition is	s 15 seconds	after program start a	s recorded mar	ually by timer	(12.396 s by p	ressure- tim	e curve) -Gl	PS97-8&9 LL	_S p. 1340 - S	See Excel workb	ook bTR426Ju	ıly2012GET	estGraph.xl	for all reading:	below			
		torr) - See Excel wo																
(0.04033	Time zero was meas	ured electronic	ally as 12.396	after the pro	gram start ar	nd occurred	~0.1 s befor	re the initial p	ressure rise								
		Sample bottle 07192																
		Representative gas p									is closed) - G	PS97-8&9 L	LS p.1340					
		Metering valve MV2																
		Near maximum elec																
		Gas pressure shortly				ing faire in r	_											
		Gas pressure after of				2011 C n 12	40											
		Gas pressure on clo						oconde hu n	manual timor	roading) after no	aram etart Cl	0907.980	I C n 12/10					
												031-003 L	Lo p. 1340					
		Close metering valve										00110-4	240					
		Electronically record					~ 19 MINUTE	s 25 s irom þ	piogram staft	uy manuai reco	ius - 6259/-{	оан ш5 р.1	J4U					
		Gas pressure after o																
		Gas pressure after o																
		MV2 was reopened						neasured										
		Highest gas pressur																
2445.3	3 6.32848	Representative gas p	ressure on fina	plateau after o	ppening BV7 a	nd MV2 (and	d end of exp	eriment)										
.306 Manual vo	oltage readir	g shortly before open	ing the valve BV	7 to the desica	cator at 1078 s	(measured	by timer fro	m start of pr	ogram) V - Gl	PS97-8&9 LLS1	340							
		re shortly before the							,									
		of gas in Min-K calo						RV7 was one	anad etd atm	oc - SR 071000	12R is closed	2 383305						
3395 Manually	read volume	of das in Min-K caio							and and attack	OD 074000								
									ened std atm	cc - SB 071920	12B is closed	- Alternate	metnod					
9346 Manually	read total w	lume of gas including							ened std atm	cc - SB 071920	12B is closed	- Alternate	metnod					
		lume of gas including	both sample b	ottles shortly b	efore opening	valve to desi	ccator std a	ıtm cc			12B is closed	- Alternate	metnod					
			both sample b	ottles shortly b	efore opening	valve to desi	ccator std a	ıtm cc			12B is closed	- Alternate	metnod					
3101 Electronic	cally read pr	lume of gas including	both sample b ore the valve to	ottles shortly b he desiccator	efore opening BV7 was oper	valve to desi ned 1149.8 s	ccator std a	etm cc zero torr - Se	e GPS97-8&	9 LLS p. 1340				j				
3101 Electronic 0815 Electronic	cally read pr	lume of gas including essure in torr just bef	both sample b ore the valve to calorimeter and	he desiccator gas handling s	efore opening BV7 was oper system 1149.8	valve to desi ned 1149.8 s s after time	ccator std a after time a zero just b	etm cc ero torr - Se efore the des	ee GPS97-8&	.9 LLS p. 1340 BV7 was opene	d std atm cc -			j				
3101 Electronic 0815 Electronic	cally read pr	lume of gas including essure in torr just bef ume of gas in Min-K	both sample b ore the valve to calorimeter and	he desiccator gas handling s	efore opening BV7 was oper system 1149.8	valve to desi ned 1149.8 s s after time	ccator std a after time a zero just b	etm cc ero torr - Se efore the des	ee GPS97-8&	.9 LLS p. 1340 BV7 was opene	d std atm cc -		011 is close	j				
8101 Electronic 0815 Electronic 0766 Electronic	cally read pr cally read vo cally read to	lume of gas including essure in torr just bef ume of gas in Min-K	both sample b pre the valve to calorimeter and led 1149.8 s aff	he desiccator gas handling s er time zero ju	BV7 was oper system 1149.8 st before the d	valve to desi ned 1149.8 s s after time lesiccator va	after time a zero just b lve BV7 wa	etm cc ero torr - Se efore the des	ee GPS97-8&	.9 LLS p. 1340 BV7 was opene	d std atm cc -		011 is close	j				
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Figure B-5. Gas evolution from LCCM flight test heat paper in physical contact with BaCrO₄.

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Appendix C. Testing of Zr-based Gas Getters

This appendix shows examples of Excel sheet analyses that were used to evaluate the effectiveness of Zr-based gas getters in atmospheres of pure hydrogen (section C-1, figure C-1) and in a hydrogen/air gas mixture (section C-2, figures C-2 and C-3). Some gas volume calculations were repeated using alternate methods to check for internal consistency.

C-1. Hydrogen Gas Gettering from a Pure Hydrogen Atmosphere – Getter Tested as Received

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sity of zi	conium	g/cc							59.996	0.007618								
ount of g	etter use	d g GPS9	7-8&9 LLS	p. 1199					119.996	0.002568								
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sure at	10 secor	ds from p	rogram sta	rt if no hyd	rogen remove	d - atm												
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Figure C-1. Hydrogen gas gettering from a pure hydrogen atmosphere.

C-2. Hydrogen Gas Gettering from a Hydrogen/Air Mixture

_			Basic Procedure										
	ndling system (GHS) and stainle	ss steel (SS) tuhe		with helium to no	minally 120 P	SIG, then th	e getter was	heated to	700 C under	helium in	he SS tuhe	e to drive off H2)
IIE OO TUDI	e was then allowed to cool to 30					,	J						
	nd sample bottle were then evac			ed in the 10 cc san	nple bottle by	closing BV6	- VBGET LL	S p.73a					
	ystem was then evacuated and f								was flushed	and filled v	vith dry roo	m air at 1 atm	
	ystem was then sealed while co						,						
	en opened, allowing the H2 and				mixture reacte	d with the a	etter materia	l which had	d been held	under vacu	um at 300	C	
	re-time voltage trace shown in th												
	bottle remained open during mo									1558.5	500.ug u.	riaan, zogan	
	econds, the gas remaining in th			boloro tiro procour	7 Too ording the	oo nao otop	pod di 1000.	0 00001140		1000.0			
1 1000.0 0	coords, the gas remaining in the	o oyotom wao 1007	End Basic Procedure										
1	Volumes of the stainless steel b	nat and the netter a			e calculations								
	Pressure of One Atmosphere (lb		are small and are not inclu	ucu iii tiitooc voiuii	c calculations								
	Pressure of One Atmosphere Pa												
	Maximum pressure reading of M												
	Maximum output voltage of MKS												
	Maximum output voltage of Mics Atmospheric pressure torr	rianouucti V											
	Atmospheric pressure torr Transducer reading at one atmos	nhoro V											
	Transducer reading at one almos Absolute temperature K at 0 dec												
			VDCET II C nn 77 70										
	Room temperature during experi				e la de la la	1 14				0			
	Tube furnace temperature readin										, ,		
	Tube furnace temperature readin	•	of ~11 inches of the 0.3/5	inch diameter 55	tude that cont	ained the ge	etter in its ce	ntrai area v	vniie cieanir	ig getter st	inace C		
	Physical volume of hydrogen in s				. V VD0FT	110 74	774405						
	MKS manual readout for H2 in 1		at room temperature before	e start of experime	ntv-vku-l								
00 00540	/ I / IIO I' '	contract to	·		III V VDOLI	LLS p.14	7714.25		10.15033				
	Volume of H2 used in experimen		DOFTILO A LODGO			LLS p.14	7/14.25		10.15033				
26.0039 I	Measured internal volume of bas	ic GHS cc - See V				LLS p.14	7/14.25		10.15033				
26.0039 I 24.07785	Measured internal volume of bas Volume of dry room air (dew poir	ic GHS cc - See Vi nt -56.3 C) used in	experiment std atm cc			шо р.74	//14.25		10.15033				
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26.0039 24.07785 20.39407	Measured internal volume of bas Volume of dry room air (dew poir	ic GHS cc - See Vi nt -56.3 C) used in used in experiment	experiment std atm cc		3, p. 1265	LLS p.74	7/14.25		10.15033				
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26.0039 24.07785 20.39407 118.063 1.0635	Measured internal volume of bas Volume of dry room air (dew poir Volume percent of dry room air u Total gas used in experiment (hy MKS manually measured transd	ic GHS cc - See VI nt -56.3 C) used in used in experiment vdrogen plus dry rou ucer voltage just be	experiment std atm cc om air) std-atm-cc efore BV2 was opened to e	7-8&9 LLS p. 1258	3, p. 1265 063 ed getter to th	e H2/air mix	ture at expe		t V - VBGE	TLLS p. 77	,		
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Figure C-2. Gas gettering from a hydrogen/air mixture.

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		before the initial p					-			-					folder on L	S13294)	
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Figure C-3. Gas gettering from a hydrogen/air mixture.

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- 3 EAGLE PICHER TECHNOLOGIES, LLC ATTN C LAMB ATTN J FERRARO ATTN M STEELE PO BOX 47 JOPLIN MO 64802
- 3 ENERSYS ADVANCED SYSTEMS
 ATTN D SWANSON
 ATTN P SCHISSELBAUER
 ATTN T HURST
 104 ROCK RD
 HORSHAM PA 19044
- 1 ILIKA TECHNOLOGIES
 ELEC EMTERPRISE ROAD
 ATTN G CARR
 UNIVERSITY OF SOUTHAMPTON
 SCIENCE PARK
 SOUTHAMPTON SO16 7NS
 UNITED KINGDOM
 - 1 INVENTEK
 ATTN T KAUN
 320 WILLOW ST
 NEW LENOX IL 60451
 - 1 LECLANCHE, S A
 ATTN P REUTSCHI
 48 AVENUE DE GRANDSON
 YVERDON-LES-BAIN CH-1401
 SWITZERLAND

NO. OF COPIES ORGANIZATION

- OMNITEK PARTNERS, LLC
 ATTN R T MURRAY
 111 W MAIN STREET STE 112
 BAYSHORE NY 01706-8313
- 1 RAYTHEON MISSILE SYSTEMS ATTN D DICKHERBER TU BLDG 805 M/S C4 1151 E HERMANN'S RD TUCSON AZ 85706
- 1 TECHNION
 ATTN N HAIMOVICH
 DEPT OF CHEM ENG
 HAIFA 32000
 ISRAEL
- THE ENSER CORPORATION
 ATTN E DAYALAN
 ATTN J PUGH
 ATTN N SHUSTER
 5430 70TH AVE N
 PINELLAS PARK FL 33781-0707

22 HCS US ARMY RSRCH LAB 4 CDS ATTN IMAL HRA 2 PDFS MAIL & RECORDS MGMT ATTN RDRL CIO LL TECHL LIB ATTN RDRL CIO LT TECHL PUB ATTN RDEL SED C W BEHL ATTN RDRL SED C M S DING (2 CDS) ATTN RDRL SED C F KRIEGER (10 HCS, 2 CDS, 2 PDFS) ATTN RDRL SED C C LUNDGREN ATTN RDRL SED C J SWANK ATTN RDRL SED E SHAFFER ATTN RDRL SED J HOPKINS ATTN RDRL SES A J PRICE ATTN RDRL SES S A LADAS ATTN RDAR MEF FA D ERRERA ATTN RDAR MEF FA W KONICK ADELPHI MD 20783-1197

TOTAL: 80 (70 HCS, 2 ELEC, 4 CDS, 4 PDFS)